CSI 4124 / SYS 5110
MODELLING & SIMULATION

Fall 2018
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University of Ottawa

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Toy Airplane Manufacturing

Problem Description

Problem Statement

A toy company produces three different types of toy aluminum airplanes (Spitfire, F-16, and Concorde). The planes are made on a production line that consists of four different types of stations and operating personnel. Operating personnel are responsible for different roles: operating some of the machines, maintaining them, moving bins, and moving boxes.

The combination of machine and personnel in the production line needs to take into consideration the limitations of the floor space, each machines capacity in terms of input and output, the personnel required to operate each machine, the processing time at each station, and the time to move parts between stations. Inefficient combinations of machines and personnel and can result in potential production bottlenecks, production operating under capacity, or idle resources not needed.

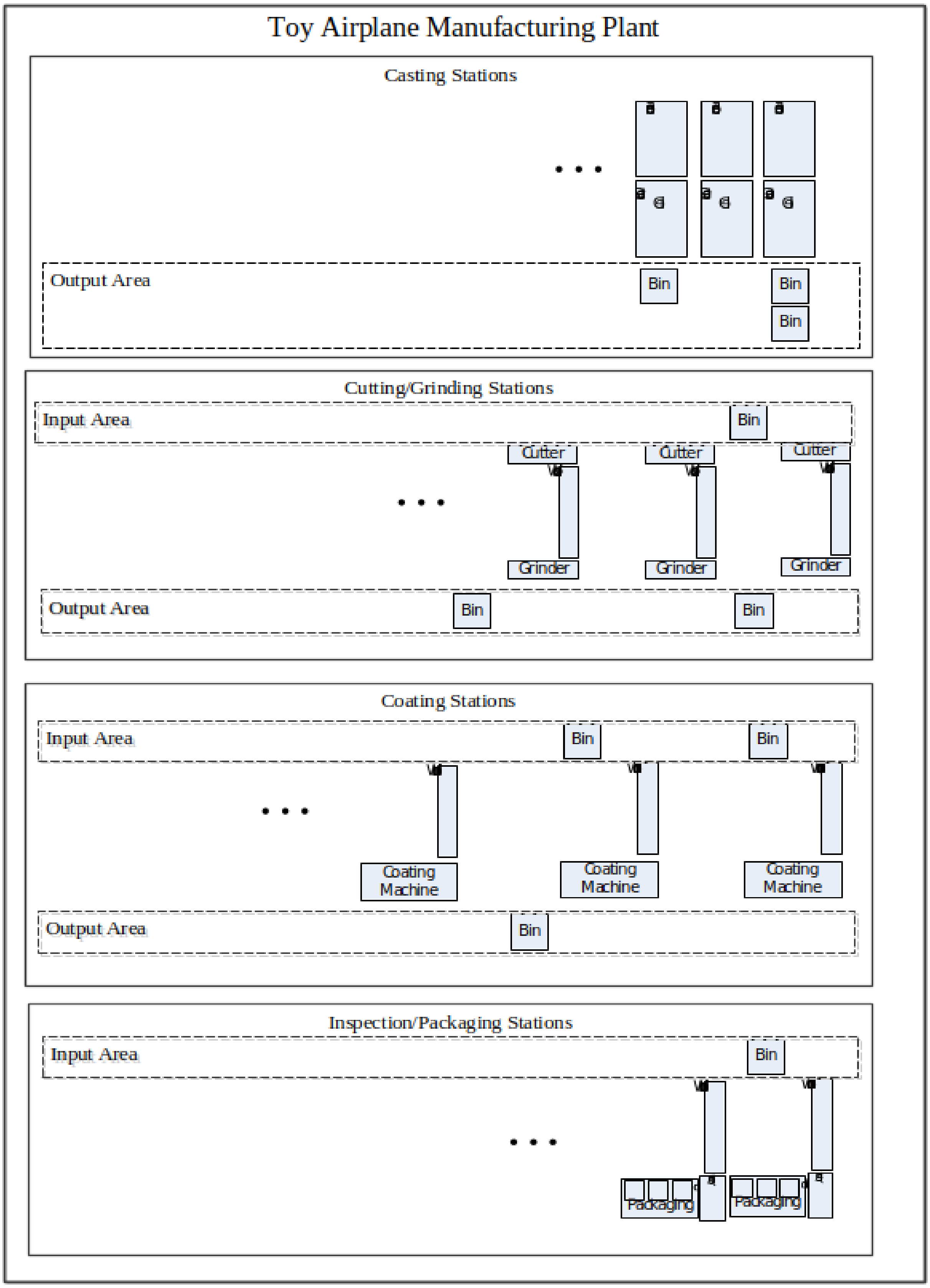
Management would like to know the possible combinations of machines and personnel that would have manufacturing capacity capable of meeting a 30% increase in demand in six months.

SUI Detail

Plant Layout and Resources

The layout of the manufacturing plant with the types of stations, along with their respective input and output areas, is shown in Figure 1. The operating personnel are not illustrated.

Figure 1. Manufacturing Plant Layout



Planes

The production line produces three types of toy-airplanes Concorde , F-16 , Spitfire.

F-16

Concorde

Spitfire

Stations

The structure of the company's manufacturing plant currently consists of a production line with four different types of stations, the characteristics of the stations are described:

1. **Casting:** A casting station consists of an aluminum holding furnace and an automated cold-chamber die caster. The die caster contains the die to produce one of the airplane types: Spitfire, F-16, and Concorde.

2. **Cutting/grinding:** A cutting/grinding station is setup with a workbench, an aluminum laser cutter and a grinding wheel. The cutter is used to separate individual planes from a die cast, and the grinder is used to remove defects after cutting.

3. **Coating:** A coating station consists of a workbench and an aluminum coating machine. The coating machine is used to anodize batches of aluminum toy-airplanes.

4. **Inspection/packing:** An inspection station consists of an inspection workbench and a packing post where plans are inspected and packed in boxes for shipping.

Manufacturing Plant Floor

The manufacturing plant floor has space for up to 80 stations. That is, a maximum of 20 casting stations, 20 cutting/grinding stations, 20 coating stations, and 20 inspection/packing stations in the production line.

Each station is designed to hold up to 5 bins for input and 5 bins for its output. Note that casting station do not require input other than molten aluminium and Inspection/packaging station do not have a output for bins. These capacities are summarized below.

Station	Input Area Bins	Output Area Bins
Casting Station	N/A	5
Cutting/Grinding Station	5	5
Coating Station	5	5
Inspection/Packaging Station	5	N/A

Operating Personnel

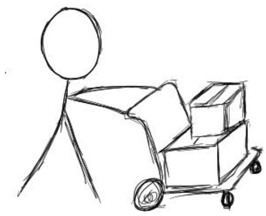
The production line runs with the assistance of various types of operating personnel with different functions, the responsibilities of these operating personnel are described:

1. **Operator:** A personnel who operates a specific machine. Each machine operates independently of one another and requires an operator with specialized training. Stations that require operators are: Cutting/Grinding, Coating and Inspection/Packaging.

2. **Mover:** A personnel who operates a trolley to move bins from one station to another. Each trolley has a capacity of 3 bins and the mover waits for his trolley to be filled with bins before proceeding to the next station.

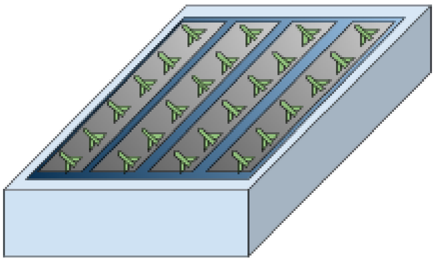
3. **Maintenance Person:** A person whose job is to provide maintenance to the die casting machines when they break down. There is only one maintenance person in the plant for repairing all the die casting stations.

4. **Warehouse Personnel:** A warehouse personnel is responsible for clearing finished product from the plant floor at regular intervals by removing full boxes from the Inspection and Packaging station.

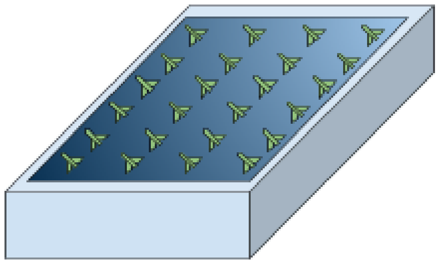


Other Resources
In addition to machines and personnel the production line requires supplementary material and resources to carry out production, described below:

1. **<u>Bins:</u>** Bins are used to move toy-airplanes, under different stages of production, from one station to the next. Bins are capable of holding: 4 casting of 6 planes each (equivalent to 24 toy-airplanes in total), or simply 24 toy-airplanes.



Bin holding 4 castings



Bin holding 24 toy-airplanes

2. **<u>Trolleys:</u>** All bins are moved by means of trolleys, which can hold up to 3 bins each, and are moved by Moving personnel when the trolleys are full.

3. **<u>Packing Boxes:</u>** Finished airplanes which have passed inspection are put in packing boxes, which can hold up-to 48 toy-airplanes.

Production Line Operations

The company operates five days a week, for eight hours per day. The production line begins empty each day and at the end of the eight hours is kept running until all the stations are empty.

Production starts at the Casting station that produce planes, which are subsequently moved to the Cutting/Grinding station, then to the Coating station, and finally to the Inspection/Packaging station. Note that, spitfire type planes do not undergo coating and are moved directly from the input of the Coating station to the output without processing.

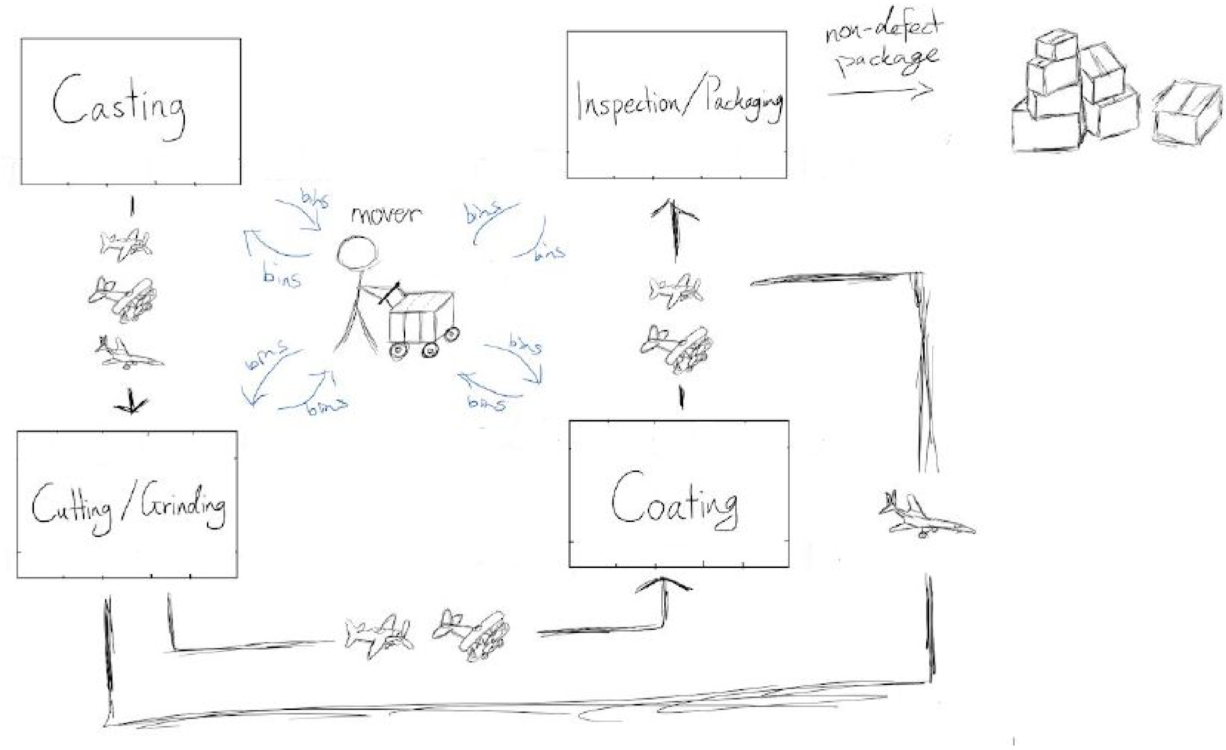
Moving Planes/Bins along the Production Line

Depending on the type of plane being made the models in production can take one of two possible routes through the production line:

A) **Concordes** and **F-16's** take the path:
   Casting station to Cutting/Grinding station to Coating station to Inspection/Packing station to Warehouse
B) While **Spitfires** skip the coating station and take the path:
   Casting station to Cutting/Grinding station to Inspection/Packing station to Warehouse

Below is a simplified diagram showing these alternative flows of planes along the production line.

Figure 2. Production Line Overview



Model planes are moved between stations in bins. Moving personnel are responsible for moving these bins between stations by loading them on trolleys which hold up to 3 bins. Movers will pick up full bins for the output area of a station and load them onto a trolley, until their trolley is full. The Movers will then take their trolley to the next station's input area. Where they will unload their trolley by distributing the bins evenly. If the input area of the receiving station is full, the mover waits until there is space available in the input area. The mover only heads to next station, where they repeat these step, when their trolley is empty. That is, 3 bins of airplanes are unloaded to the station. Overall this means that loaded bins are moved between stations three at a time.

To cover the entire production line, Mover personnel are responsible for circulating bins through the plant by cycling through the following steps:

1. Moving bins from the output areas of the Casting Stations to the input areas of the Cutting/Grinding stations.
2. Moving bins from the output areas of the Cutting/Grinding stations to the input areas of the Coating stations, in the case of the F-16 and Concorde planes. Spitfire planes are moved directly to the input area of the Inspection/Packing Station.
3. Moving bins from the output areas of the Coating Stations to the input areas of the Inspection/Packing Stations.
4. Move empty bins from the Inspection/Packing Stations back to the Casting stations.

Station Operations

There are four different types of stations which are responsible for different stages of the model airplanes production, their behavioural operations are described:

1. **<u>Casting Station:</u>**

    Each Casting Station produces one type of airplane. The die caster injects a precise amount of molten aluminum metal from a holding furnace into molds that produce a casting of 6 airplanes. The casts are put in bins of 4 casts, that are placed in the output area of the station. The Casting station can become blocked when the output area becomes full. In addition, Die casters experience regular downtimes, during which the molten aluminum is returned to the aluminum furnace. After being repaired the machine restarts a new casting of planes. Takes 3 minutes to cast 6 airplanes. If the output area is full, the caster waits until space is available before continuing.

2. **Cutting/Grinding Station:**
   A casting of 6 planes produce by a die caster must be separated from each other and grinded to remove any defects from the casting and cutting operations. The four castings from a bin in the input area are processed and the resulting 24 airplanes are placed back in the bin which is put into the output area of the station. If the output area is full, the operator waits until space is available before continuing.

3. **Coating Station:**
   Only F-16 and Concorde toy airplanes require this operation. The operator obtains the 24 planes from a bin in the input area of the station and places it into the coating machine to anodize the planes. The planes are then placed back into the bin in the output area. It takes 12 mins to anodize 24 airplanes of type F-16 or type Concorde. If the output area is full, the operator waits until space is available before continuing.

4. **Inspection and Packaging Station:**
   Planes must be inspected before they are packed. The station operator obtains 24 planes from a bin in the input area of the station and inspects the airplanes for defects. Those that meet inspection are packaged into an appropriate box. Those that do not meet inspection are placed in a reject bin. Packed boxes are automatically collected to the warehouse and do not accumulate in the output area.

Assignment Roles

The following team has been assembled to model the system under investigation (SUI).

Team Leader

- Hussein Sakr, 7897706

Conceptual Modelling (CM) Team

- Jonathan Calles, 8906650
- Wenjing Chen, 6999821
- Hedwin Bonnavaud, 300096335

Simulation (SM) Team

- Hanchen He, 300083336
- Kaiyi Zhang, 300070775
- Hussein Sakr, 7897706

Experimentation and Analysis (EA) Team

- Hussein Sakr, 7897706
- Jonathan Calles, 8906650
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- Hedwin Bonnavaud, 300096335

Project Goal

The goal of the simulation project is to determine the possible combinations of machines and personnel that defines a production capacity capable of meeting the increase in demand that management requires, i.e. 130% of the current production output.

Parameters

The quantity of stations and personnel in the production line of the toy company.

Stations

Given that the manufacturing plant can only hold up to 20 of each kind of station, and noting that a die casting station can only produce one type of airplane at a time, a minimum of 3 die casting stations are required. The following parameters will be used to control the number of stations in the model:

Parameter	Description	Value
numCastingStationsSpitfire	The number of Casting Stations for Spitfire production.	Each parameter having a minimum value of 1 and a maximum sum of all parameters value of 20.
numCastingStationsF16	The number of casting stations for F-16 production.	
numCastingStationsConcorde	The number of casting stations for Concorde production.	
numCuttingGrindingStations	The number of Cutting/Grinding Stations.	Where the values of this parameter has a range of 1 to 20.
numCoatingStations	The number of Coating Stations.	Where the values of this parameter has a range of 1 to 20.
numInspectionPackagingStations	The number of Inspection/Packing Stations.	Where the values of this parameter has a range of 1 to 20.

Personnel

The number maintenance staff is fixed at 1, while the number of warehouse personnel is of no consequence to the production output. The number of station operators is derived from the number of stations. Therefore, only the number of moving personnel can be adjusted as a parameter:

Parameter	Description	Value
numMovers	The number of Moving Personnel.	Where the values of this parameters has a range of 1 to 20.

Experimentation

Study: Bounded Horizon Study, as the goal is to observe how many planes can be produced during the observation interval.

Observation Interval:
The factory operates eight hours a day and five days a week. At the end of the eight hours the production line is kept running until all the stations are empty.

- Time units: minutes
- Observation interval: One operational day.
    - Begins at t=0 min.
    - At t = 480 mins the production line is kept running until the stations are emptied.
    - The end of the observation interval will be when all the stations have run empty after t = 480 mins.

Experimentation: The current quantity of stations and personnel in the manufacturing plant is unknown, however this is unimportant as the target production numbers are known.

Type of Toy Airplane	Current Production per day (100%)	Target Production per day (130%)
Spitfire	1000	1300
F-16	1500	1950
Concorde	1800	2340

Algorithmic Approach

Our objective is to find the minimum number of stations and moving personnel required to produce the target daily production within the eight hour work day. First, the number of stations required will be determined. Secondly, the optimal number of movers to assist this quantity of stations will be determined.

Determining the number of Casting Stations

1. To find the lower bound of daily production the parameters for each casting station type we start by setting all casting stations to a minimum and the rest of the stations to a maximum:
    a. numCastingStationsSpitfire = 1
    b. numCastingStationsF16 = 1
    c. numCastingStationsConcorde = 1
    d. numCuttingGrindingStations = 20
    e. numCoatingStations = 20
    f. numInspecitonPackingStations = 20
2. To calibrate the number of stations accurately we will begin with a comfortable number of movers, to ensure that a lack of movers is not causing any bottlenecks.
    a. numMovers = 20
3. A simulation will be run to see if the desired production outputs of each toy are reached. If the production numbers area below target the number of casting stations will be incremented, adding a casting station of the type under target. Casting station will be only increment by 1 at a time for each simulation until desired output is reached.
4. Repeat step 3 until desired target production numbers are reached. If the target production has been reached proceed to the next phase

Determining the number of Coating Stations

1. The number of coating stations will be determined first due to the lack spitfire type planes needing such stations. Logically, there will be less production demand from coating stations then the other types of stations.
2. A simulation will be run to see if the desired production outputs of each toy are maintained. If the target production is maintained the number of coating stations will be decremented by one.
3. Repeat step 2 until production is below the desired output for any of the planes, this will indicate the lower threshold. Increment the number of coating stations back-up by one, and take this value as the minimum number of coating stations required.

Determining the number of cutting/grinding stations

1. The number of cutting/grinding stations will be determined next due to the chance of being blocked unlike inspection/packaging stations which can not be blocked.
2. A simulation will be run to see if the desired production outputs of each toy are maintained. If the target production is maintained the number of cutting/grinding stations will be decremented by one.
3. Repeat step 2 until production is below the desired output for any of the planes, this will indicate the lower threshold. Increment the number of cutting/grinding stations back-up by one, and take this value as the minimum number of cutting/grinding stations required.

Determining the number of Inspection/packaging stations

1. The number of inspection/packaging stations will be determined next instead of the number of movers due to the constraint that we have on the number of stations.
2. A simulation will be run to see if the desired production outputs of each toy are maintained. If the target production is maintained the number of inspection/packing stations will be decremented by one.
3. Repeat step 2 until production is below the desired output for any of the planes, this will indicate the lower threshold. Increment the number of inspection/packing stations back-up by one, and take this value as the minimum number of inspection/packing stations required.

Determining the number of movers

1. Finally, the number of movers is determined.
2. A simulation will be run to see if the desired production outputs of each toy are maintained. If the target production is maintained the number of movers will be decremented by one.
3. Repeat step 2 until production is below the desired output for any of the planes, this will indicate the lower threshold. Increment the number of movers back-up by one, and take this value as the minimum number of moverss required.

This deterministic method will find the configuration of stations and the number of movers needed to meet the target daily production, *within official operating hours*.. However it remains understood, that overtime will still be incurred to clear the stations at the end of the day, but by that point it is guaranteed that target daily production has already been met.

Output

In order to tune the parameters for the next simulation each simulation will result in the percentage of target daily production produced for each type of airplane.

Output Value	Description
percentTargetProductionConcorde	The amount of target daily production produced, for Concorde airplanes, as a percentage.
percentTargetProductionF16	The amount of target daily production produced, for F-16 airplanes, as a percentage.
percentTargetProductionSpitfire	The amount of target daily production produced, for Spitfires airplanes, as a percentage.

Annex A (Data Models)

Table 1. Empirical Station Operating Times

	Operation	Operation Time	Station
1	Die casting	3 min (output 6 airplanes) The die caster experiences downtimes every 60 minutes exponentially distributed and takes 8 minutes normally distributed with a standard deviation of 2 minutes to repair. One maintenance person is always on duty to make repairs.	Automated die caster
2a	Cutting	Triangular (0.25, 0.28, 0.35) minutes per airplane	Cutting/Grinding Station
2b	Grinding	Sample times (min per airplane): 0.23, 0.22, 0.26, 0.22, 0.25, 0.23, 0.24, 0.22, 0.21, 0.23, 0.20, 0.23, 0.22, 0.25, 0.23, 0.24, 0.23, 0.25, 0.47, 0.23, 0.25, 0.21, 0.24, 0.22, 0.26, 0.23, 0.25, 0.24, 0.21, 0.24, 0.26	Cutting/Grinding Station
3	Coating	12 min per batch of 24 airplanes	Coating Station
4	Inspection and packaging	Triangular (0.27, 0.30, 0.40) minutes per airplane	Inspection/Packaging Station 88% of planes pass inspection

Table 2. Inter-station Moving Times

Moving from Output Area to Input Area	Moving Time
Casting Stations to Cutting/Grinding Stations	0.85 minutes
Cutting/Grinding Stations to Coating stations	0.43 minutes
Coating Stations to Inspection/Packaging Stations	0.41 minutes
From Inspection/Packing Stations to the Casting Stations	1.35 minutes

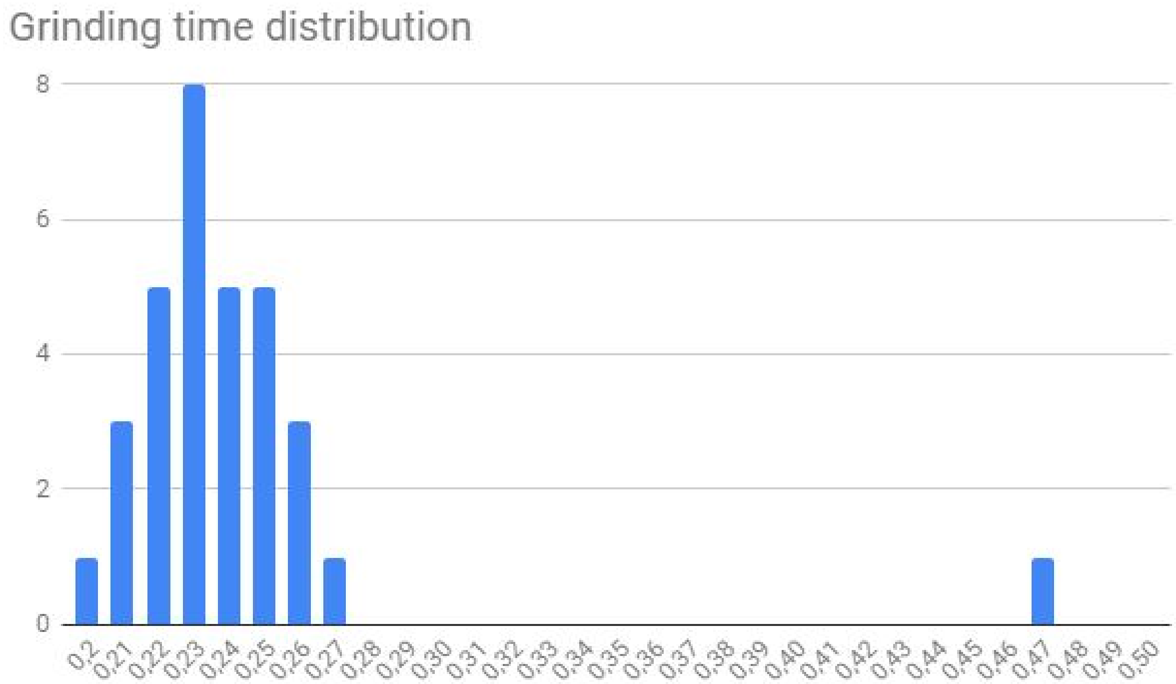
Station Operating Times

The operating times of each station is subject to variations. Fortunately, the operating times have been studied in the past, and it is known that the process times follow particular distributions:

1. **Casting**: Three kinds of airplanes have their own corresponding die caster. 6 airplanes are produced in 3 mins. The die caster experiences downtimes every 60 minutes exponentially distributed and takes 8 minutes normally distributed with a standard deviation of 2 minutes to repair.

2. **Cutting**:
   The time to cut a plane is triangular distribution:
   We know the values of a(min), b(max), and c (mean).
   a = 0.25, b = 0.35 and c = 0.28

3. **Grinding**:
   According to the grinding sample times, we can get the grinding time generation shape.



According to this graph, We are going to test three candidates :

- Exponential distribution.
- Normal distribution,
- Gamma distribution,

Then we can make a chi-square test to try to find which one of them is the good one.

This if the table comparing our result with the attempted one. And with the sum of differences between these two values for each class, we just have to accept or not the distribution

EXPONENTIAL LAW		NORMAL LAW		GAMMA LAW	
μ	0,240967742	μ	0,240967742	μ	0,240967742
σ	0,0617	σ	0,0617	σ	0,0617
Var	0,00380689	Var	0,00380689	Var	0,00380689
λ	4,149933066			a	43
				λ	178,4471218
k	5	k	5	k	4
g	1	g	2	g	2
v	3	v	2	v	1
Am	141,5640844	Am	37,02009981	Am	12,251139
level of sig'	7,81	level of sig'	5,99	level of sig'	3,84
				1/T	84,49944215
				T	0,011834398
n	31	n	31	n	31
Am	level of sig	Am	level of sig	Am	level of sig
141,564084	7,81	37,0200998	5,99	12,251139	3,84
Difference :	-133,754084	Difference :	-31,0300998	Difference :	-8,411139

This table represent the results of our tests. According to them, we can see Am which is the difference between the value of each class. This value have to be less than the level of significance to accept the distribution. And then, we can see that the Gamma distribution isn't far, but Am value for this distribution is still far from what we're searching for.

Then all these distribution aren't correct, so we can try to create an empirical one.

Value	Time appear	Frequency
0.20	1	0,03225806
0.21	3	0,09677419
0.22	5	0,16129032
0.23	8	0,25806452
0.24	5	0,16129032
0.25	5	0,16129032
0.26	3	0,09677419
0.47	1	0,03225806

Then we just have to create our own distribution with this data, $p(Value) = Frequency$ according to the table above. Then it's possible to have a 0.47 value but not a value of 0.27, which is really far from the reality, so empirical distribution isn't the good solution. In order to stay closer to the reality, we will use the Gamma distribution, which is the closest we have.

Then this Gamma distribution is going to take parameters $a = 43, \lambda = 178.447$

4. **<u>Inspection</u>**: The time to inspect an airplane is triangular distribution:
   We know the values of a(min), b(max), and c(mean).
   a = 0.27, b = 0.40 and c = 0.30
   Only 88% airplanes could pass the inspection.

ABCmod Conceptual Model

High Level Conceptual Model

Assumptions

Given ambiguous or incomplete information available from the case study, the following assumptions are being made to clarify the SUI:

Personnel

A. It is assumed that factory space is not an issue to accommodate personnel such as Movers.
B. It is assumed that there is one operator needed per inspection and packaging station.

Stations

C. It is assumed that the company has sufficient supplies of aluminum, such that the casting stations never have to wait for aluminum.
D. It is assumed that the company has sufficient supplies of boxes, such that the inspection/packing station never have to wait for empty boxes.
E. It is assumed that spitfire bins when moved from the output section of cutting/grinding station will not be dropped off at a coating station. That is, spitfire bins will remain with the mover when they go to input section of coating station. Likewise, at the output of the coating station the mover will reload their trolley with three bins - including the amount of spitfire bins already held - before proceeding to the input section of the inspection/packaging station.
F. We will assume that warehouse personnel will also be responsible for emptying out reject bins, and this is being done on a continuous basis.

Operations

G. It is assumed that the company has sufficient supplies of bins, such that there is never a shortage of bins to circulate in the production line.

Simplifications

In order to capture the essential characteristics of the SUI that will address the project goal, the SUI is being modelled with the following simplifications:

Personnel

A. All personnel will be working non-stop during the observation interval (i.e. all personnel will be present and working, and will not take breaks or fall ill).
B. Station operators will be modelled together with their respective stations, as there is a one-to-one ratio which does not affect production output. This applies the manned stations, cutting, coating, inspection and packing.
C. Movers will be modelled together with their respective trolleys, as there is a one-to-one ratio which does not affect production output.
D. As warehouse personnel are external to the production process, they will not be explicitly modelled or counted towards the number of personnel needed for production.

Stations

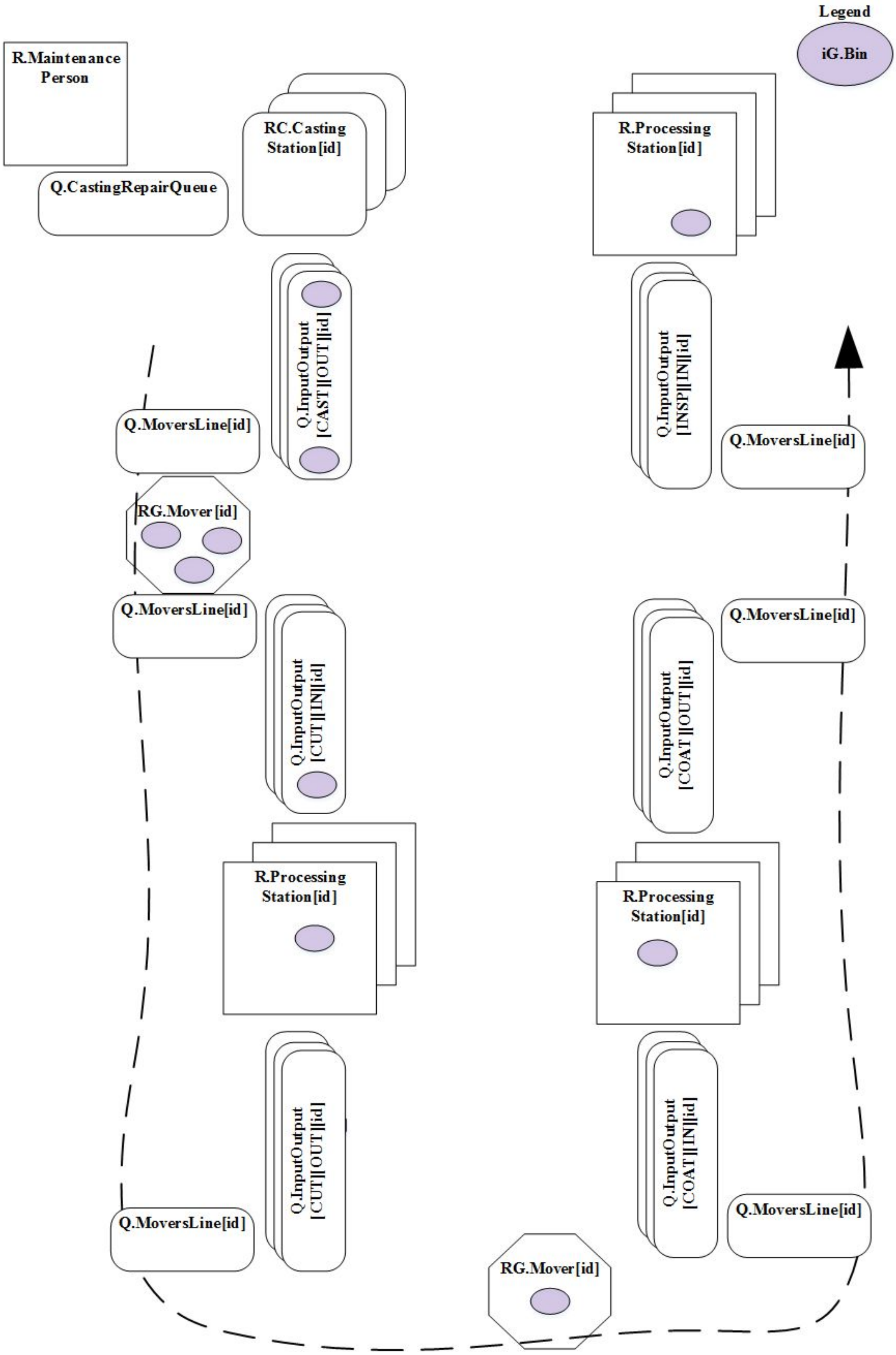
E. The queues in the various Output areas and Input areas will be modelled as the same type of entity with scope SET, as both they provide exactly the same functionality with respect to holding bins.
F. The time taken for warehouse personnel empty reject bins located in the input area of the inspection/packing station will be instantaneous.

Operations

G. The time taken to load and unload bins from trolleys will be considered instantaneous.
H. The time it takes for the Maintenance person to switch from repairing one Casting Station to the next Casting Station shall be considered instantaneous.
I. No data was provided for the following movements, and will therefore be considered instantaneous: Movers traveling from the input area to output area of the cutting/grinding station, as well as traveling from the input area to output area of the coating station.
J. After the eight hour working day machines and operators work until all stations are empty.
K. The availability of bins should not affect production, to achieve this bins will be modelled as transient. Meaning that bins are always available to enter the model at the die casting stations where planes are produced, and empty bins returning to the casting stations from the inspection/packing station will not be explicitly modelled. Bins picked up from the Inspection/Station will essentially leave the model, and the step where movers circulate from the inspection/packing station back to the casting station will model movers only

Structural View

Figure 3. Manufacturing Plant Structural Diagram



Entity Categories

1. **Furnace and Die Casting Station - RC.CastingStation**
   A resource consumer entity that represents a set of a furnace with a die caster in the casting stations, where casts of airplanes are produced from molten aluminum. The entity has the *scope=Set[numOfStations].*
   Description:
   Note that numOfStations is the sum of numCastingStationsSpitfire + numCastingStationsF16 + numCastingStationsConcorde, which are all parameters.
   E.g.
   RC.CastingStation[numCastingStationsSpitfire + numCastingStationsF16 + numCastingStationsConcorde]

   RC.CastingStation[5]: the 5th casting station.

2. **CutGrind / Coat / InspectPack Stations - R.ProcessingStation**
   A resource entity that represents a set of cutting/grinding, coating and inspection stations. The entity has the *scope=Set[3][numOfStations].*
   Description:
   The first identifier of the set indicates the type of station (CUT, COAT, INSP).
   The second identifier *numOfStations* varies and indicates the number of stations for the given station type. Note that numOfStations is specified by one of the parameters numCuttingGrindingStations, numCoatingStations, or numInspectionPackingStations as appropriate.
   E.g.
   R.ProcessingStation[CUT][numCuttingGrindingStations]
   R.ProcessingStation[COAT][numCoatingStations]
   R.ProcessingStation[INSP][numInspectionPackingStations]

   R.ProcessingStation[CUT][8]: the 8th cutting/grinding station
   R.ProcessingStation[INSP][9]: the 9th inspection/packing station

3. **Input/Output Areas - Q.IOArea**
   A queue entity that represents either the input or output area of a station where bins wait until they are processed by the station or are picked up by movers as appropriate. The entity has the *scope=Set[4][2][numOfStations].*
   Description:
   The first identifier of the set indicates the area of the plant floor (CAST, CUT, COAT, INSP) where the queue is located. The second identifier indicates if the queue is an input or output queue (IN or OUT), and the third identifier indicates to which specific station the queue is associated with. The value of numOfStations depends on the area and is given by the parameters: numCastingStations, numCuttingGrindingStations, numCoatingStations and numInspectionPackingStations as appropriate.

E.g.
Q.IOArea[CUT][IN][numCuttingGrindingStations]
Q.IOArea[CUT][OUT][numCuttingGrindingStations]
Q.IOArea[COAT][IN][numCoatingStations]
Q.IOArea[COAT][OUT][numCoatingStations]

Q.IOArea[COAT][IN][10]: the input queue associated to 10th coating station.
Q.IOArea[INSP][IN][11]: the input queue associated to 11th inspection/packaging station.
Q.IOArea[CAST][OUT][12]: the output queue associated to 12th casting station.
Q.IOArea[CUT][OUT][13]: the output queue associated to 13th cutting/grinding station.

4. **Movers with Trolleys - RG.Mover**
   A resource group entity that represents moving personnel along with their respective trolleys whom move bins between stations. The entity has the *scope=Set[numMovers]*, where numMovers is a parameter.

5. **Bin - iG.Bin**
   A transient group entity that represents the bins that hold airplanes in their various stages of production, so that they can be moved between stations. The entity has the *scope=Class.*

6. **Maintenance Person - R.MaintenancePerson**
   A resource entity that represents the sole maintenance person who provides maintenance to the die casters in the casting stations when they break. The entity has the *scope=Unary*.

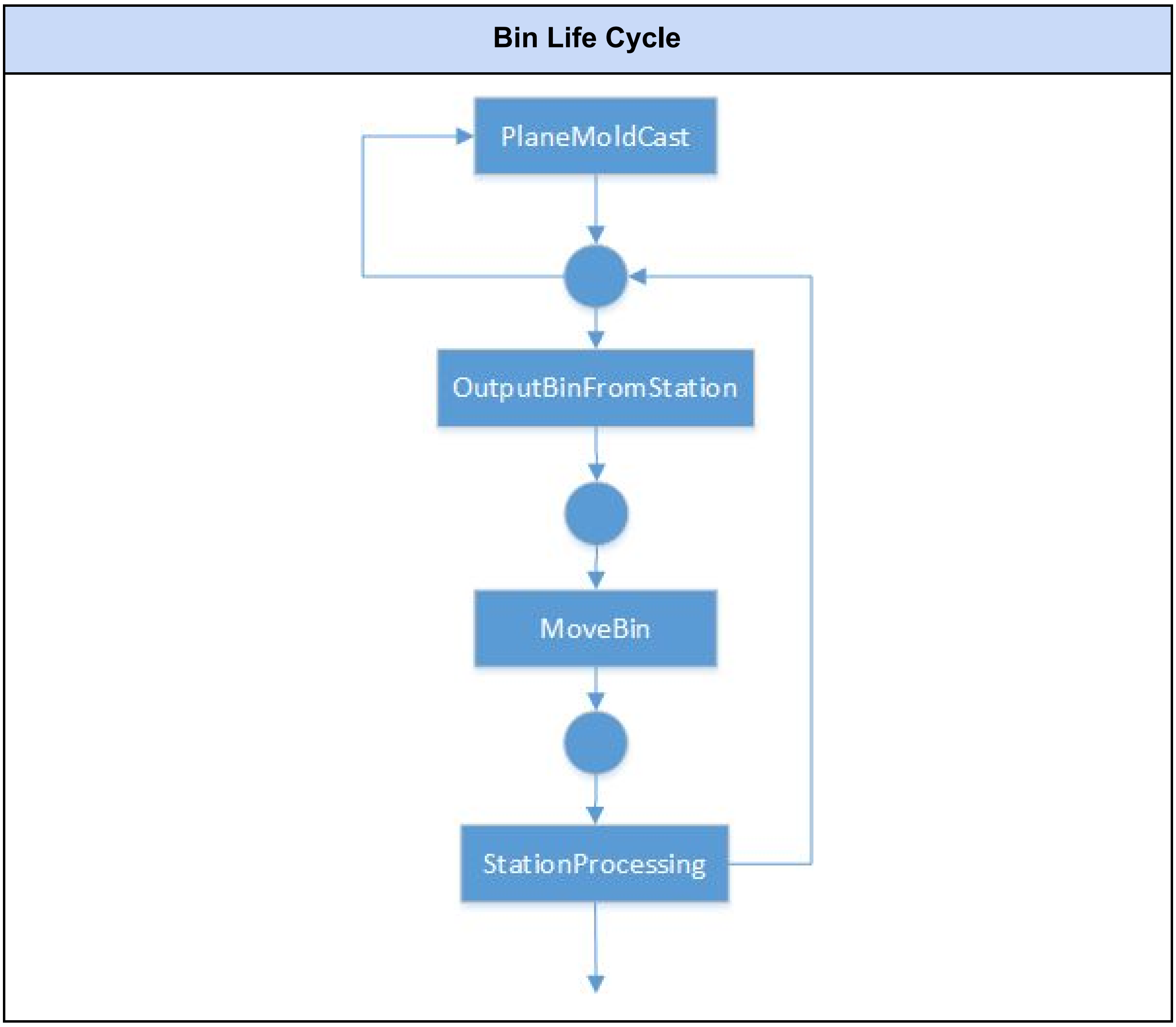
7. **Casting Station Repair Queue - Q.CastingRepairQueue**
   A queue entity that represents the Casting Stations that need maintenance and are awaiting repairs from the Maintenance Person. The entity has the *scope=Unary*.

8. **Movers Line - Q.MoversLine**
   A queue entity that represents movers waiting at a station’s input or output area, to either drop-off bins or to pick-up bins. The entity has the *scope=Set[4][2]*
   Description:
   The first identifier of the set indicates the area of the plant floor (CAST, CUT, COAT, INSP) where the line is located. The second identifier indicates if the line is for movers dropping-off bins, or picking-up bins (IN or OUT).

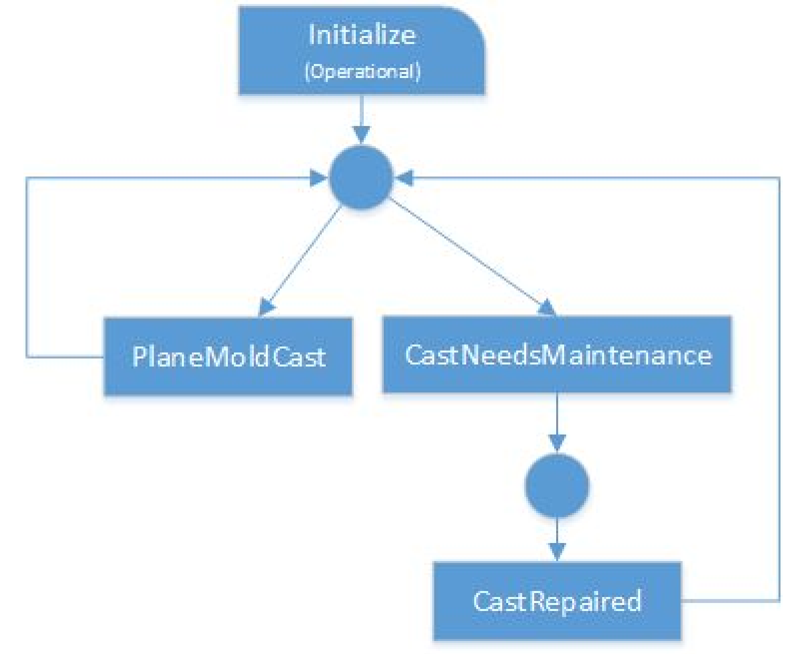
E.g.
Q.MoversLine[CAST][OUT]: the line of movers picking-up bins from the outputs queues of the casting stations.
Q.MoversLine[CUT][IN]: the line of movers dropping-off bins to the input queues of the cutting/grinding stations
Q.MoversLine[CUT][OUT]: the line of movers picking-up bins from the outputs queues of the cutting/grinding stations.
Q.MoversLine[INSP][IN]: the line of movers dropping-off bins to the input queues of the inspection/packing stations

Behavioural View

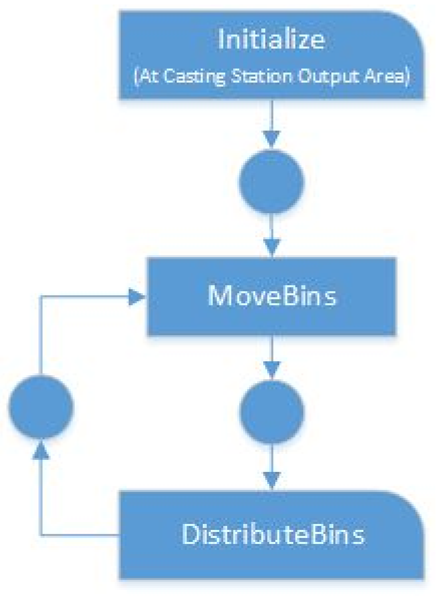
Figure 4. Entity Life Cycle



Casting Machine Life Cycle



Mover Life Cycle



Actions and Activities:
The actions and activities illustrated in the behavioural life cycles are explained below.

Conditional	Description
PlaneMoldCast	Die Casting machines automatically produces one die cast of 6 airplanes, when the machine is operational.
CastNeedsMaintenance	Casting machines experience downtime approximately every 60 minutes. A casting machine is considered in need of maintenance if there is not sufficient time to cast planes before the die-caster will break, or if the die caster has already broken.
CastRepaired	The maintenance person takes approximately eight minutes to fix 1 die casting machine.
StationProcessing	**Cutting/Grinding Station** Cutter operator cuts 6 airplanes from one die cast. Grinder operator grinds the defects on 1 airplane. **Coating Station** Coating operator uses a machine to anodize 24 airplanes in a single batch. **Inspection/Packing Station** Inspector inspects 1 plane for defects. If the plane was shown to be defective, it is placed in a reject bin. If the plane passes inspection it is placed in a packing box.
OutputBinFromStation	Once a bin has been processed by a station and has reached its capacity of 24 airplanes, it is transferred to the output area of the station, if there is space in the output area.
MoveBins	A mover at an output area will load bins onto their trolley, if they have space on their trolley. They will prioritize collecting bins from the fullest output queues. They will wait until bins become available, if there are not enough bins to fill their trolley.

	If a mover at an output area who has a full trolley will travel from the output area of the station, to the input area of the next station.
DistributeBins	A mover at an input area will unload bins from their trolley, distributing them evenly, if there is with space available in the input area. They will wait until space becomes available, if the input area is full. After unloading a mover will advance from the input area of a station to the output area of the station. (Note: spitfires are not unloaded at the Coating Station). In the case of the Inspection/Packing Station, the mover will proceed to the output area of the Casting Station instead.

Input

There are no Exogenous inputs to this model. The Endogenous Inputs are listed.

Endogenous Input (Semi-Independent)		
Variable Name	**Description**	**Value(s)**
uCastingBreakTime	The time it takes for a die cast machine to break from its last reparation.	RVP.uCastingBreakTime()
uCastingRepairTime	The time it takes for the maintenance person to fix 1 die casting machine.	RVP.uCastingRepairTime()
uOperationTime	The time it take for the grinding/cutting, coating and inspection/packing operations.	RVP.uOperationTime(areaID)
uNumPlanesAccepted	The pass rate of planes which pass inspection.	RVP.uNumPlanesAccepted()
uMoveBetweenStationsTime	The time it takes for a Mover to travel from one station to the next station.	DVP.uMoveBetweenStationsTime(currentStation, destinationStation)

Detailed Conceptual Model

Structural Components

The constants and parameters that will be used to model the SUI are listed.

Constants		
Name	**Description**	**Value(s)**
CAST, CUT, COAT, INSP	Identifiers for set categories RC.CastingStation, R.ProcessingStation, Q.IOArea, and Q.MoversLine The identifiers serve to associate each RC.Casting / R.ProcessingStation entity with a Q.IOArea entity and a Q.MoverLine entity.	0,1,2,3
IN, OUT	Identifiers for set categories RC.CastingStation, R.ProcessingStation, Q.IOArea, and Q.MoversLine The identifiers serve to associate each RC.Casting / R.ProcessingStation entity with a Q.IOArea entity and a Q.MoverLine entity.	0,1
BIN_CAP	The maximum number of planes that can be held in a bin.	24
MOVER_CAP	The maximum number of bins that can be held in a trolley by a Mover.	3
IN_OUT_CAP	The maximum number of bins that can be held in an input / output area	5
CASTING_TIME	The time it takes for a Casting Station to produce a die cast equivalent to 6 airplanes.	3 min
COATING_TIME	The time it takes for a Coating Station to anodize a batch of 24 airplanes.	12 min
NO_BIN	A placeholder value to indicate a Casting Stations / Processing Stations does not hold any bin.	null
NONE	A default placeholder value to indicate no permissible values available.	-1
NO_RESULT	A default placeholder value to indicate non-existence.	null
PlaneType	One value from the the collection of airplane	Enmueration

<table>
<tr><td></td><td>types being produced.</td><td>{SPITFIRE, CONCORDE, F16}</td></tr>
<tr><td>StationStatus</td><td>One value from the collection of possible statuses that a Casting Station / Processing station can be in.</td><td>Enumeration {IDLE, BUSY, NEEDS_MAINTENANCE}</td></tr>
<tr><th colspan="3">Parameters</th></tr>
<tr><th>Name</th><th>Description</th><th>Value</th></tr>
<tr><td>numCastingStationsSpitfire</td><td>The number of Casting stations for Spitfire production.</td><td rowspan="3">3 to 20 in total

We will reference this total by totalNumberOfCastingStations.

Each parameter having a minimum of 1.</td></tr>
<tr><td>numCastingStationsF16</td><td>The number of Casting Stations for F-16 production.</td></tr>
<tr><td>numCastingStationsConcorde</td><td>The number of Casting Stations for Concorde production</td></tr>
<tr><td>numCuttingGrindingStations</td><td>The number of Cutting/Grinding Stations in the production line.</td><td>1 to 20</td></tr>
<tr><td>numCoatingStations</td><td>The number of Coating Stations in the production line.</td><td>1 to 20</td></tr>
<tr><td>numInspectionPackagingStations</td><td>The number of Inspection/Packing Stations in the production line.</td><td>1 to 20</td></tr>
<tr><td>numMovers</td><td>The number of Moving Personnel assisting the production line.</td><td>1 to 20</td></tr>
</table>

The structural components of the conceptual model are detailed below.

Resource Consumer Set[numCastingStations]: CastingStation	
A resource consumer entity that represents a set of a furnace with a die caster in the casting stations, where casts of airplanes are produced from molten aluminum.	
Attribute	**Description**
type	The assigned value indicates the type of airplane being casted. Three values are possible: SPITFIRE, F16, CONCORDE
status	Identifies the current status of the station. Three values are possible:IDLE, BUSY, NEEDS_MAINTENANCE
timeToNextBreak	Counts down the time until the next diecast break from its last reparation.
bin	References a bin entity at the station. Set to NOBIN to indicate a bin is not present at the station.

Resource Set[stationType][numOfStations]: ProcessingStation	
the first identifier is set to one of CUT, COAT, INSP and indicates the area where the station is located and the second identifier numOfStations is the stationId of given type station. If stationType is CUT, numOfStations is numCuttingGrindingStations. If stationType is COAT, numOfStations is numCoatingStations. If stationType is INSP, numOfStations is numInspectionPackagingStations.	
Attribute	**Description**
status	Identifies the current status of the station. Two values are possible:IDLE, BUSY
bin	References a bin entity at the station. Set to NOBIN to indicate a bin is not present at the station.

Queue Set[stationType][IN or OUT][numberStations]: IOArea	
A queue entity that represents either the input or output area of a station where bins wait until they are processed by the station or are picked up by movers as appropriate. If stationType is COAT, numberStations is totalNumberOfCastingStations. If stationType is CUT, numberStations is numCuttingGrindingStations. If stationType is COAT, numberStations is numCoatingStations. If stationType is INSP, numberStations is numInspectionPackagingStations.	
Attribute	**Description**
n	The number of bins in the input area or the output area.
list	The list of bin entities in the input area or the output area. Discipline: FIFO

Resource Group Set[numMovers]: Mover	
A resource group entity that represents moving personnel along with their respective trolley whom move bins between stations.	
Attribute	**Description**
n	The number of bins in the trolley.
trolley	The array of bin entities in the trolley.

Group Class: Bin	
A group entity that represents the bins that hold 24 airplanes in their various stages of production, so that they can be moved between stations.	
Attribute	**Description**
type	The assigned value indicates the type of airplane in the bin. Three values are possible: SPITFIRE, F16, CONCORDE
n	The number of planes in the bin.

Resource Unary: MaintenancePerson	
A resource entity that represents the sole maintenance person who provides maintenance to the die casters in the casting stations when they break.	
Attribute	**Description**
available	Identifies that the maintenance person is available to fix a die caster. Set to TRUE when the maintenance person is available and FALSE otherwise.

Queue Unary: CastingRepairQueue	
A queue entity that represents the Casting Stations that need maintenance and are awaiting repairs from the Maintenance Person.	
Attribute	**Description**
n	The number of Casting Machines waiting to be repaired.
list	The list of station ids of Casting Station entities. Discipline: FIFO

Queue[areaId][IN OR OUT]: MoversLine	
A queue entity that represents movers waiting at a station's input or output area, to either drop-off bins or to pick-up bins.	
Attribute	**Description**
n	The number of movers in the queue.
list	The list of mover entities in the queue. Discipline: FIFO

Behavioural Components

Time units: minutes
Observation interval: $t_0 = 0$, Implicit Stop Condition: (t >= 480 minutes (8 hour business day); AND planes are no longer being manufactured (i.e. all stations are idle).

Action: Initialise	
Initialise the model, all Casting Stations start idle with an empty bin, all Processing Stations are idle and empty, all movers are at the Casting output area with empty trolleys, the maintenance person is available.	
Time Sequence	< 0 >

Event SCS	**Initialise Parameters**
	totalNumberOfCastingStations ← numCastingStationsSpitfire
	+
	numCastingStationsF16
	+
	numCastingStationsConcorde
	numSpit ← numCastingStationsSpitfire
	numF16 ← numCastingStationsF16
	numConcorde ← numCastingStationsConcorde
	
	num ←0
	
	WHILE(num < totalNumberOfCastingStations)
	    Initialise Casting Station of type Spitfire
	    IF (numSpit>0) THEN
	        RC.CastingStation[num].type ← SPITFIRE
	        RC.CastingStationnum].status ← IDLE
	        RC.CastingStation[num].timeToNextBreak
	←RVP.uCastingBreakTime()
	        iG.Bin ← SP.Derive(Bin)
	        iG.Bin.type ← SPITFIRE
	        iG.Bin.n ← 0
	        RC.CastingStation[num].bin ← iG.Bin
	        num←num+1
	        numSpit←numSpit-1
	    ENDIF
	
	    Initialise Casting Station of type F16
	    IF(numF16>0) THEN
	        RC.CastingStation[num].type ← F16
	        RC.CastingStation[num].status ← IDLE
	        RC.CastingStation[num].timeToNextBreak ←
	RVP.uCastingBreakTime()
	        iG.Bin ← SP.Derive(Bin)
	        iG.Bin.type ← F16
	        iG.Bin.n ← 0
	        RC.CastingStation[num].bin ← iG.Bin
	        num←num+1

	numF16←numF16-1
	ENDIF
	
	Initialise Casting Station of type Concorde
	IF(numConcorde>0) THEN
	RC.CastingStation[num].type ← CONCORDE
	RC.CastingStation[num].status ← IDLE
	RC.CastingStation[num].timeToNextBreak ← RVP.uCastingBreakTime()
	iG.Bin ← SP.Derive(Bin)
	iG.Bin.type ← CONCORDE
	iG.Bin.n ←0
	RC.CastingStation[num].bin ← iG.Bin
	num←num+1
	numConcorde←numConcorde-1
	ENDIF
	ENDWHILE
	
	Initialise all the Output Queues for the Casting Stations
	FOR CastId FROM 0 to totalNumberOfCastingStations
	Q.IOArea[CAST][OUT][CastId].n ← 0
	ENDFOR
	
	Initialise all the Cutting/Grinding Stations.
	FOR CutId FROM 0 to numCuttingGrindingStations-1
	R.ProcessingStation[CUT][CutId].status ← IDLE
	R.ProcessingStation[CUT][CutId].bin ← NOBIN
	Q.IOArea[CUT][IN][CutId].n ← 0
	Q.IOArea[CUT][OUT][CutId].n ← 0
	ENDFOR
	
	Initialise all the Coating Stations.
	FOR CoatId FROM 0 to numCoatingStations-1
	R.ProcessingStation[COAT][CoatId].status ← IDLE
	R.ProcessingStation[COAT][CoatId].bin ← NOBIN
	Q.IOArea[COAT][IN][CoatId].n ← 0
	Q.IOArea[COAT][OUT][CoatId].n ← 0
	ENDFOR
	
	Initialise all the Inspection/Packing Stations.
	FOR InspId FROM 0 to numInspectionPackingStations-1
	R.ProcessingStation[INSP][InspId].status ← IDLE
	R.ProcessingStation[INSP][InspId].bin ← NOBIN
	Q.IOArea[INSP][IN][InspId].n ← 0
	ENDFOR
	
	Q.MoversLine[CAST][OUT].n ← 0
	Q.MoversLine[CUT][IN].n ← 0
	Q.MoversLine[CUT][OUT].n ← 0
	Q.MoversLine[COAT][IN].n ← 0

	Q.MoversLine[COAT][OUT].n ← 0 Q.MoversLine[INSP][IN].n ← 0 **Initialise all the Movers.** FOR moverId FROM 0 to numMovers-1 RG.Mover[x].n ←0 RG.Mover[x].trolley ← 0 SP.InsertQue(Q.MoversLine[CAST][OUT], moverId) ENDFOR **Initialise the Maintenance Person and the Repair Queue for Casting Stations.** R.MaintenancePerson.available ← TRUE Q.CastingRepairQueue.n ← 0

Output

OUTPUTS	
Simple Scalar Output Variables (SSOV's)	
Name	**Description**
percentTargetProductionConcorde	The amount of target daily production produced, for Concorde airplanes, as a percentage. numConcordeProduced is used to calculate the total number of concorde produced.
percentTargetProductionF16	The amount of target daily production produced, for F-16 airplanes, as a percentage. numF16Produced is used to calculate the total number of F16 produced.
percentTargetProductionSpitfire	The amount of target daily production produced, for Spitfires airplanes, as a percentage. numSpitfireProduced is used to calculate the total number of spitfire produced.

Input Constructs

Random Variate Procedures (RVP)		
Name	**Description**	**Data Model**
RVP.uCastingBreakTime()	The time it takes for a die cast machine to break from its last reparation.	The casting time is sampled from: EXPONENTIAL(CASTING_BREAK_MEAN) Where CASTING_BREAK_MEAN = 60 min
RVP.uCastingRepairTime()	The time it takes for the maintenance person to fix 1 die casting machine.	The repair time is sampled from: NORMAL(RT_MEAN_TIME_TO_REPAIR, RT_STD_DEV_TIME_TO_REPAIR) Where RT_MEAN_TIME_TO_REPAIR = 8 min RT_STD_DEV_TIME_TO_REPAIR = 2 min
RVP.uOperationTime[areaID]	The time it take for the grinding/cutting, coating and inspection/packing operations.	**areaID is CAST:** The operation time is CASTING_TIME. **areaID is CUT:** The operation time is the total time to cut and grind 24 airplanes from a bin, sampled from: Cutting time per plane: TRIANGULAR(CT_LOWER_TIME_TO_CUT, CT_MODE_TIME_TO_CUT, CT_UPPER_TIME_TO_CUT) Grinding time per plane: GAMMA(GT_ALPHA, GT_LAMBDA) Where CT_LOWER_TIME_TO_CUT = 0.25 min CT_MODE_TIME_TO_CUT = 0.28 min CT_UPPER_TIME_TO_CUT = 0.35 min GT_ALPHA = 43 min GT_LAMBDA = 178 min **areaID is COAT** The operation time is COATING_TIME.

		areaID is INSP: The operation time is the total time to inspect 24 airplanes from a bin, sampled from: Inspection time per plane: TRIANGULAR(IT_LOWER_TIME_TO_INSPECT, IT_MODE_TIME_TO_INSPECT, IT_UPPER_TIME_TO_INSPECT) Where IT_LOWER_TIME_TO_INSPECT = 0.27 min IT_MODE_TIME_TO_INSPECT = 0.30 min IT_UPPER_TIME_TO_INSPECT = 0.40 min
RVP.uNumPlanesAccepted()	Check if the airplane passed the inspection. Returns either TRUE or FALSE.	Returns TRUE, if the airplane pass the inspection otherwise,Returns FALSE, PERCENT_PASS = 0.88
Deterministic Variate Procedures (DVP)		
Name	**Description**	**Data Model**
DVP.uMovingBetweenStationsTime(currentAreaID, destinationAreaID)	The time it takes for a Mover to travel from one station to the next station.	Returns the move time from the following table: CurrentAreaID DestinationAreaID Time to Travel (min) CAST CUT 0.85 CUT COAT 0.43 COAT INSP 0.41 INSP CAST 1.35

Behavioural Constructs

Activity: PlaneMoldCast	
Die Casting machines automatically produces one die cast of 6 airplanes, when the machine is operational.	
Precondition	UDP.CastingStationReadyForProcessing() ≠ NONE
Event SCS	stationID ← UDP.CastingStationReadyForProcessing() RC.CastingStation[stationID].status ← BUSY
Duration	RVP.uOperationTime(CAST)
Event SCS	RC.CastingStation[stationID].status ← IDLE RC.CastingStation[stationID].bin.n **+** ← 6 RC.CastingStation[stationID].timeToNextBreak **-** ← CASTING_TIME

User-Defined Procedure	
Name	**Description**
CastingStationReadyForProcessing()	Returns the identifier, stationID, of a member of RC.Casting[numCastingStations] that is ready for casting operations under the following conditions: ○ RC.CastingStation[stationID].status is IDLE ○ RC.CastingStation[stationID].bin.n < BIN_CAP ○ The production line is still within operating hours (i.e. before the end of the eight hour work day) ○ RC.CastingStation[stationID].timeToNextBreak>CASTING_TIME If no such RC.Casting is ready for operations, the procedures returns NONE.

Activity: CastNeedsMaintenance	
Casting machines experience downtime approximately every 30 minutes exponentially distributed. A casting machine is considered in need of maintenance if there is not sufficient time to cast planes before the die-caster will break, or if the die caster has already broken.	
Precondition	UDP.CastingAboutToBreak() ≠ NONE
Event	stationID ← UDP.CastingAboutToBreak() RC.CastingStation[stationID].status ← NEEDS_MAINTENANCE
Duration	RC.CastingStation[stationID].timeToNextBreak
Event	SP.InsertQue(Q.CastRepairQueue, RC.CastingStation[stationID])
User-Defined Procedure	
Name	**Description**
CastingAboutToBreak()	Returns the identifier, stationID, of a member of RC.CastingStation[numCastingStations] that is about to break down under the following conditions: • RC.CastingStation[stationID].timeToNextBreak < CASTING_TIME • RC.CastingStation[stationID].status is IDLE otherwise, the procedures returns NONE.

Activity: CastRepaired	
Casting machine undergoes repairs by the Maintenance Person. After the station has been repaired it is reset so that is ready to begin casting dies.	
Precondition	Q.CastingRepairQueue.n ≠ 0 AND R.MaintenancePerson.available = TRUE
Event SCS	stationID ← SP.RemoveQue(Q.CastRepairQueue) R.MaintenancePerson.available ← FALSE
Duration	RVP.uCastingRepairTime()
Event SCS	RC.CastingStation[stationID].status ← IDLE RC.CastingStation[stationID].timeToNextBreak ← RVP.uCastingBreakTime() R.MaintenancePerson.Available ← TRUE

Activity: StationProcessing	
The cutting/grinding, coating and inspection/packing stations operations respective to each type of station. All these stations undergo different operations summarized in one activity.	
Precondition	UDP.StationReadyForOperation() ≠ NO_RESULT
Event SCS	<areaID, stationID> ← UDP.StationReadyForOperation() R.ProcessingStation[areaID][stationID].status ← BUSY R.ProcessingStation[areaID][stationID].bin ← SP.RemoveQue(Q.IOarea[areaID][IN][stationID])
Duration	RVP.uOperationTime(areaID)

Event SCS	R.ProcessingStation[areaID][stationID].status ← IDLE
	IF (areaID = INSP) THEN
	
	FOR x FROM 0 to IN BIN_CAP-1
	IF(RVP.uNumPlanesAccepted()=TRUE)
	SWITCH (R.ProcessingStation[areaID][stationID].bin.type)
	CASE CONCORDE
	numConcordeProduced+ ←1
	CASE F16
	numF16Produced+ ←1
	CASE SPITFIRE
	numSpitfireProduced+ ←1
	ENDIF
	ENDFOR
	
	SP.Leave(R.ProcessingStation[areaID][stationID].bin)
	R.ProcessingStation[areaID][stationID].bin ← NOBIN
	ENDIF

User-Defined Procedure	
Name	**Description**
StationReadyForOperation()	Returns the identifiers, areaID and stationID, of a member of R.ProcessingStation[areaID][numOfStations] that is ready for operations under the following conditions: ○ R.ProcessingStation[areaID][stationID].status is IDLE ○ R.ProcessingStation[areaID][stationID].bin is NOBIN ○ Q.IOArea[areaID][IN][stationID].n ≠ 0 If no such R.ProcessingStation[areaID][stationID] is ready for operations, the procedures returns NO_RESULT.

<table>
<tr><th colspan="2">Action: OutputBinFromStation</th></tr>
<tr><td colspan="2">Once a bin has been processed by a station and has reached its capacity of 24 airplanes, it is transferred to the output area of the station, if there is space in the output area.

Does not apply to Inspection/Packing Stations, as planes which pass inspection are packed in boxes, or placed in reject bins, which are automatically cleared by warehouse staff. Inspection/Packing Stations do not have output areas.</td></tr>
<tr><td>Precondition</td><td>UDP.BinReadyForOutput() ≠ NO_RESULT</td></tr>
<tr><td>Event</td><td><areaId, stationId> ← UDP.BinReadyForOutput()
IF (areaId = CAST) THEN
SP.InsertQue(Q.IOArea[areaID][OUT][stationId],
RC.CastingStation[stationId].bin)
RC.CastingStation[stationId].bin ← SP.Derive(Bin)
RC.CastingStation[stationId].bin.type ←
RC.CastingStation[stationId].type
RC.CastingStation[stationId].bin.n ← 0
ELSE IF(areaId!=INSP)
SP.InsertQue(Q.IOArea[areaID][OUT][stationId], R.ProcessingStation[areaId][stationId].bin)
RC.ProcessingStation[areaId][stationId].bin ← NOBIN
ENDIF</td></tr>
</table>

<table>
<tr><th colspan="2">User-Defined Procedure</th></tr>
<tr><td>Name</td><td>Description</td></tr>
<tr><td>BinReadyForOutput()</td><td>Returns the identifiers, CAST, stationID, of a member of RC.CastingStation[numCastingStations] that is holding a processed bin ready for output under the following conditions:
• RC.CastingStation[stationID].bin.n = BIN_CAP
• Q.IOArea[CAST][OUT][stationID].n < IN_OUT_CAP
• RC.CastingStation[stationID].status = IDLE

OR

Returns the identifiers, areaID, stationID, of a member of RC.ProcessingStationID[areaID][numOfStations] that is holding a processed bin ready for output under the following conditions:
• RC.ProcessingStation[areaID][stationID].bin ≠ NOBIN
• RC.ProcessingStation[areaID][stationID].status = IDLE
• Q.IOArea[areaID][OUT][stationID].n < IN_OUT_CAP

otherwise, the procedures returns NO_RESULT.</td></tr>
</table>

<table>
<tr><th colspan="3">Activity: MoveBins</th></tr>
<tr><td colspan="3">A mover at an output area will load bins onto their trolley, if they have space on their trolley. They will prioritize collecting bins from the fullest output queues. They will wait until bins become available, if there are not enough bins to fill their trolley. If a mover at an output area who has a full trolley will travel from the output area of the station, to the input area of the next station.</td></tr>
<tr><td>Precondition</td><td colspan="2">UDP.CanStartMovingBins() ≠ NONE</td></tr>
<tr><td>Event SCS</td><td colspan="2"><currentAreaID> ← UDP.CanStartMovingBins()
moverID ← SP.RemoveQue(Q.MoversLine[currentAreaID][OUT])
destinationAreaID ← UDP.FillTrolley(moverID, currentAreaID)</td></tr>
<tr><td>Duration</td><td colspan="2">DVP.uMovingBetweenStationsTime(currentAreaID, destinationAreaID)</td></tr>
<tr><td>Event SCS</td><td colspan="2">SP.InsertQue(Q.MoversLine[destinationAreaID][IN], moverID)</td></tr>
<tr><th colspan="3">User-Defined Procedure</th></tr>
<tr><td colspan="2">Name</td><td>Description</td></tr>
<tr><td colspan="2">CanStartMovingBins()</td><td>Returns the identifiers, areaID, of a member of Q.MoversLine[areaID][OUT] if there is a mover available at the head of the line to pick up bins from the stations’ output areas’ and there are sufficient bins to fill that movers trolley under the following conditions:
● Q.MoversLine[areaID][OUT].n ≠ 0
● There are enough bins available to fill the movers trolley from the stations’ output areas’.

OR

If it is past the end of the production line’s operation hours (after the eight hour work day):
● Q.MoversLine[areaID][OUT].n ≠ 0
● The stations’ are all IDLE
● The stations’ output is not empty

Otherwise, the procedure returns NONE.</td></tr>
<tr><td colspan="2">FillTrolley(moverID, currentAreaID)</td><td>Returns the destination, destinationAreaID, and loads bins from output area onto the mover’s trolley.
Add bins from the longest output queues (with biggest output)</td></tr>
</table>

	(Q.IOArea[currentAreaId][OUT][StationId]) until the trolley is full.
	
	Where
	destinationAreaID ← UDP.uNextStation(currentAreaID)
	
	IF(currentAreaID=CUT AND all the three Bin.type is SPITFIRE in the trolley)
	destinationAreaID=INSP *//Skip the COAT station*
	ENDIF

NextStation(currentAreaID)	Returns the next station from the following table: CurrentAreaID DestinationAreaID CAST CUT CUT COAT COAT INSP INSP CAST

Action: DistributeBins	
A mover at an input area will unload bins from their trolley, distributing them evenly, if there is with space available in the input area. They will wait until space becomes available, if the input area is full. After unloading a mover will advance from the input area of a station to the output area of the station. (Note: spitfires are not unloaded at the Coating Station). In the case of the Inspection/Packing Station, the mover will proceed to the output area of the Casting Station instead.	
Precondition	UDP.CanDistributeBins() ≠ NONE

Event	areaId ← UDP.CanDistributeBins()
	moverId ← SP.RemoveQue(Q.MoversLine[areaId][IN])
	UDP.emptyTrolley(moverId,areaId)
	IF(currentAreaID = INSP) THEN
	    SP.InsertQue(Q.MoversLine[CAST][OUT], moverID)
	ELSE
	    SP.InsertQue(Q.MoversLine[currentAreaID][OUT], moverID)
	ENDIF

User-Defined Procedure	
Name	**Description**
emptyTrolley(moverId,areaId)	Unloads the bins from the movers trolly and distributes them evenly into the input queues of the area (Q.IOArea[areaId][IN][stationId). The input queues are selected according to the following rules: 1) Always select the shortest queue 2) IF queues are empty (Q.IOArea[areaId][IN][stationId.n=0) then select the queue where the station is not busy (R.ProcessingStation[areaId].status = IDLE).
CanDistributeBins()	Returns the identifier, areaID, of a member of Q.MoversLine[areaID][IN] if there is a mover available at the head of the line to drop off bins at the stations' input areas' under the following conditions: • Q.MoversLine[areaID][IN].n ≠ 0 • There is enough space available in the stations' input areas' to unload bins from the movers trolley (Not including Spitfires at the Coating Stations). Otherwise, the procedure returns NONE.

Design and Validation Experimentation

Given the various moving parts of the model, the state of the Simulation model will monitored and validated using an output log.

Trace Logging

The output log will display the

- Type, status, and time-to-break of each Casting Station (RC.CastingStation.type, RC.CastingStation.status) along with how many bins are in its output area (Q.IOArea.n)
- Status, and bin of each Processing Station (R.ProcessingStation.type, R.ProcessingStation.bin) along with how many bins are in its respective input and output areas (Q.IOArea.n)
- The quantity of movers lined up at each station input/output area (Q.MoversLine.n)
- The availability of the Maintenance Person (R.MaintenancePerson.available)
- The quantity of Casting Stations in queue to be repaired (Q.CastingRepairQueue.n)

Output format:
The format of the output trace log will emulate the general layout of the manufacturing plant layout, so that entities and status changes can be followed visually. For example { } will represent a queue.

The output log will use the following legend to make the information concise and easier to read:

S = 1 spitfire bin
C = 1 concorde bin
F = 1 F16 bin
M = 1 mover
TTB = Time to Break

Likewise the following variables will be replaced with the appropriate information or designated attribute values:

YYY = Station status {IDLE, BUSY, NEEDS_MAINTENANCE}
XXX = Time, in minutes.
NP = the number of planes cast
NM = the number of movers in line

```
Clock = xxx
------------SBL-------
----------------------

            INPUT AREA      STATION           OUTPUT AREA

   SPITFIRE      CAST 0 : yyy   [NP]    {  S  }      TTB = xxx  min
   F16                 CAST 1 : yyy   [NP]    {  F  }      TTB = xxx  min
   CONCORDE            CAST 2 : yyy   [NP]    {  C  }      TTB = xxx  min
                                                   {MMMMMMMMMMMMMMMMMMMMM} 20
NM {     }
            {  S  }    CUT  0 : yyy   [  ]    {  F  }
                                                 {       } NM

NM {     }
            {  C  }    COAT 0 : yyy   [  ]    {     }
                                                 {       } NM

NM {     }
            {     }    INSP 0 : yyy   [S ]

MAINTPER: AVAILABLE
REPAIRQ:  {                    }
```

Validation Test Cases

The model shall be validated by checking the following model functions in the output logs:

1) Model is initialized with parameter configurations.
2) Casting stations producing bins.
3) Casting stations experience regular downtime.
4) Casting stations queued for maintenance are being repaired.
5) All processing Stations obtain bins from the input areas.
6) Cutting/Grinding stations process bins.
7) Coating stations process bins.
8) Inspection/Packing stations process bins.
9) Processed bins are placed in the output areas.
10) Stations get blocked by full output areas
11) Movers move between stations according to their circulation path.
12) Movers wait at input areas until space is available
13) Movers wait at output areas until bins are available
14) Bins are distributed evenly to input areas by arriving movers.
15) Bins are removed from output areas by departing movers.
16) SpitFires are not dropped off at Coating Stations
17) Casting stations stop producing bins at the end of the working day.
18) All stations are emptied and return to idle at the end of the simulation.

Simulation Model

Design of Simulation Model and Program

The simulation model is implemented in the class **ToyManufacturingModel** (an extension of the ABSmod/J class AOSimulation model) and a number of other classes used to implement the various constructs from the ABCmod conceptual model outline in the previous sections. All Java classes that make up the Java ToyAirplane simulation model are placed in the Java package **SimModel**.

The following table shows how the various ABCmod entity structures are mapped to Java classes and how objects instantiated from these classes are referenced by the **ToyManufacturingModel** class.

Entity Structures		
ABCmod Construct	**Java Class**	**Object References**
RC.Casting Station	`CastingStation`	`ToyManufacturingModel.rcCastingStation`
R.ProcessingStation	`ProcessingStation`	`ToyManufacturingModel.rProcessingStation`
RG.Mover	`Mover` Notes: • the attribute trolley is an array of bin entities	`ToyManufacturingModel.rgMover`
iG.Bin	`Bin`	Typically by the reference variable `igBin` in the various methods that manipulate Bin objects**.**
R.MaintenancePerson	`MaintenancePerson`	`ToyManufacturingModel.rMaintenancePerson`
Q.IOArea	`ArrayList` (standard Java Class) Notes • The various methods available in the `ArrayList` object provide the	`ToyManufacturingModel.qIOArea`

	implementation of the various ABCmod procedures, such as SP.InsertQue (`qIOArea.add`) SP.RemveQue (`qIOArea.remove`). ● The attribute n is maintained within the `ArrayList` object (adjusted automatically when `ArrayList` methods are called). The method `qIOArea.size()` provides the value of the Q.IOArea.n attribute.	
Q.CastingRepairQueue	`LinkedList` (standard Java Class) Notes ● The various methods available in the `LinkedList` object provide the implementation of the various ABCmod procedures, such as SP.InsertQue (`qCastingRepairQueue.add`) SP.RemveQue (`qCastingRepairQueue.pop`). ● The attribute n is maintained within the `LinkedList` object (adjusted automatically when `LinkedList` methods are called). The method(`qCastingRepairQueue.size()`)provides the value of the Q.CastingRepairQueue.n attribute.	`ToyManufacturingModel.qCastingRepairQueue`
Q.MoversLine	`LinkedList` (standard Java Class) Notes ● The various methods available in the `LinkedList` object provide the implementation of the various ABCmod procedures, such as SP.InsertQue (`qMoversLine.add`) SP.RemveQue (`qMoversLine.pop`). ● The attribute n is maintained within the `LinkedList` object (adjusted automatically when `LinkedList` methods are called). The method (`qMoversLine.size()`)provides the value of the Q.MoversLine.n attribute.	`ToyManufacturingModel.qMoversLine`

The following table provides mapping between the conceptual model Action/Activities to Java classes.

Actions/Activities	
ABCmod Constructs	**Java Classes**
PlaneMoldCast	`PlaneMoldCast`
CastNeedsMaintenance	`CastNeedsMaintenance`
CastRepaired	`CastRepaired`
StationProcessing	`StationProcessing`
OutputBinFromStation	`OutputBinFromStation`
MoveBins	`MoveBins`
DistributeBins	`DistributeBins`

Other classes that make up the ToyManufacturingModel ABSmod/J simulation model include:

- **Output**(referenced by ToyManufacturingModel**.output**): Contains the SSOVs.
- **Constants**: Contains the model's constants.
- **RVPs** (referenced by ToyManufacturingModel**.rvp**): Contains the Java methods used to implement the CM RVP's.
- **DVPs**(referenced by ToyManufacturingModel**.dvp**): Contains the Java methods used to implement the CM DVP's.
- **UDPs**(referenced by ToyManufacturingModel**.udp**): Contains the Java methods used to implement the CM UDP's.
- **Seeds**: The class used to pass seeds for random number generators used in implementing the various RVPs.

The package SimModel provides public access to the following:

- The constructor **ToyManufacturingModel** to allow creation of the ToyManufacturingModel object, along with **Initialize** to instantiate all the entities as required by the parameter configuration.
- The methods **getNumSptfireProduced()**,**getNumF16Produced()** and **getNumConcordeProduced()** to allow access the value of the output variables numSpitfireProduced, numF16Produced and numConcordeProduced
- All public methods provided by the class **AOSimulation** (e.g. **runsimulation**) for supporting experimentation.

Results of the Validation Experimentation

The java class **ToyManufacturingModel** contains the experimentation software to generate the output logs of the simulation runs for each parameter configuration. The following screenshot highlight parts of the log that demonstrate the proper and expected behaviour of the model. Boxes and arrows have been added around the most relevant log information.

Note, the output log uses the following legend:

S = spitfire bin

C = concorde bin

F = F16 bin

M = mover

1) Model Initialized - Beginning of the Observation Interval:

The start of the log shows initialization of the modelling at t=0. When the working day begins and all the casting stations start casting airplane molds, as seen by the PlaneMoldCast activities, and all the movers are lined up at the casting area output.

```
Clock =     0.0000
------------SBL----------
TimeStamp:3.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:3.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:3.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:3.0 Activity/Action: simModel.PlaneMoldCast
----------------------
             MOVER LINE
                     INPUT AREA      STATION           OUTPUT AREA
                                                                MOVER LINE

           SPITFIRE            CAST 0 : BUSY   [0 ]   {     }       TTB = 33.28  min
           F16                 CAST 1 : BUSY   [0 ]   {     }       TTB = 105.20 min
           CONCORDE            CAST 2 : BUSY   [0 ]   {     }       TTB = 17.66  min
           SPITFIRE            CAST 3 : BUSY   [0 ]   {     }       TTB = 171.58 min
                                                         {MMMMMMMMMMMMMMMMMMMM} 20


0  {                    }
                     {     }   CUT  0 : IDLE   [  ]   {     }
                     {     }   CUT  1 : IDLE   [  ]   {     }
                     {     }   CUT  2 : IDLE   [  ]   {     }
                                                         {                    } 0


0  {                    }
                     {     }   COAT 0 : IDLE   [  ]   {     }
                     {     }   COAT 1 : IDLE   [  ]   {     }
                     {     }   COAT 2 : IDLE   [  ]   {     }
                                                         {                    } 0


0  {                    }
                     {     }   INSP 0 : IDLE   [  ]
                     {     }   INSP 1 : IDLE   [  ]
                     {     }   INSP 2 : IDLE   [  ]


MAINTPER: AVAILABLE
REPAIRQ:  {                     }
```

2) Casting Stations Produce Bins

Each PlaneMoldCast activity adds 6 airplanes to the bin in the Casting Station. So on the fourth PlaneMoldCast activity, the bin holds 24 airplanes and the bin is sent to the output area.

```
Clock =     12.0000
------------SBL----------
TimeStamp:12.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:12.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:12.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:15.0 Activity/Action: simModel.PlaneMoldCast
----------------------
             MOVER LINE
                     INPUT AREA      STATION            OUTPUT AREA
                                                                 MOVER LINE

           SPITFIRE             CAST 0 : BUSY   [0 ]    {S     }        TTB = 21.28  min
           F16                  CAST 1 : BUSY   [18]    {      }        TTB = 96.20  min
           CONCORDE             CAST 2 : BUSY   [18]    {      }        TTB = 8.66   min
           SPITFIRE             CAST 3 : BUSY   [18]    {      }        TTB = 162.58 min
                                                           {MMMMMMMMMMMMMMMMMMMMM} 20


0  {                    }
                    {     }     CUT  0 : IDLE   [  ]    {      }
                    {     }     CUT  1 : IDLE   [  ]    {      }
                    {     }     CUT  2 : IDLE   [  ]    {      }
                                                           {                    } 0


0  {                    }
                    {     }     COAT 0 : IDLE   [  ]    {      }
                    {     }     COAT 1 : IDLE   [  ]    {      }
                    {     }     COAT 2 : IDLE   [  ]    {      }
                                                           {                    } 0


0  {                    }
                    {     }     INSP 0 : IDLE   [  ]
                    {     }     INSP 1 : IDLE   [  ]
                    {     }     INSP 2 : IDLE   [  ]


MAINTPER: AVAILABLE
REPAIRQ:  {                    }
```

```
Clock =     12.0000
------------SBL----------
TimeStamp:12.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:12.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:15.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:15.0 Activity/Action: simModel.PlaneMoldCast
----------------------
             MOVER LINE
                     INPUT AREA      STATION            OUTPUT AREA
                                                                 MOVER LINE

           SPITFIRE             CAST 0 : BUSY   [0 ]    {S     }        TTB = 21.28  min
           F16                  CAST 1 : BUSY   [0 ]    {F     }        TTB = 93.20  min
           CONCORDE             CAST 2 : BUSY   [18]    {      }        TTB = 8.66   min
           SPITFIRE             CAST 3 : BUSY   [18]    {      }        TTB = 162.58 min
                                                           {MMMMMMMMMMMMMMMMMMMMM} 20
```

3) Casting Stations Downtime

When the time-to-break for a Casting Station becomes less than the time required to cast a die (3 min), the casting station is considered in need of maintenance, and a CastNeedsMaintenance activity is initiated.

```
Clock =     15.0000
------------SBL----------
TimeStamp:15.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:15.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:18.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:18.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:25.26825018343616 Activity/Action: simModel.StationProcessing
TimeStamp:25.899349969330203 Activity/Action: simModel.StationProcessing
TimeStamp:26.47731586992473 Activity/Action: simModel.StationProcessing
----------------------
             MOVER LINE
                     INPUT AREA      STATION            OUTPUT AREA
                                                                 MOVER LINE

           SPITFIRE             CAST 0 : BUSY    [6 ]    {     }      TTB = 18.28   min
           F16                  CAST 1 : BUSY    [6 ]    {     }      TTB = 90.20   min
           CONCORDE             CAST 2 : BUSY    [0 ]    {     }      TTB = 5.66    min
           SPITFIRE             CAST 3 : BUSY    [0 ]    {S    }      TTB = 159.58  min
                                                            {MMMMMMMMMMMMMMMMMMM } 19


0  {                 }
                     {     }    CUT  0 : BUSY    [S ]    {     }
                     {     }    CUT  1 : BUSY    [C ]    {     }
                     {     }    CUT  2 : BUSY    [F ]    {     }
                                                            {M                    } 1


0  {                 }
                     {     }    COAT 0 : IDLE    [  ]    {     }
                     {     }    COAT 1 : IDLE    [  ]    {     }
                     {     }    COAT 2 : IDLE    [  ]    {     }
                                                            {                     } 0


0  {                 }
                     {     }    INSP 0 : IDLE    [  ]
                     {     }    INSP 1 : IDLE    [  ]
                     {     }    INSP 2 : IDLE    [  ]


MAINTPER: AVAILABLE
REPAIRQ:  {                    }
```

```
Clock =     15.0000
------------SBL----------
TimeStamp:15.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:17.663085903114847 Activity/Action: simModel.CastNeedsMaintenance
TimeStamp:18.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:18.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:25.26825018343616 Activity/Action: simModel.StationProcessing
TimeStamp:25.899349969330203 Activity/Action: simModel.StationProcessing
TimeStamp:26.47731586992473 Activity/Action: simModel.StationProcessing
----------------------
             MOVER LINE
                     INPUT AREA      STATION            OUTPUT AREA
                                                                 MOVER LINE

           SPITFIRE             CAST 0 : BUSY    [6 ]    {     }      TTB = 18.28   min
           F16                  CAST 1 : BUSY    [6 ]    {     }      TTB = 90.20   min
           CONCORDE             CAST 2 : NMAINT  [6 ]    {     }      TTB = 2.66    min
           SPITFIRE             CAST 3 : BUSY    [0 ]    {S    }      TTB = 159.58  min
                                                            {MMMMMMMMMMMMMMMMMMM } 19
```

4) Casting Stations Repaired

Once a casting station has been repaired, its status is no longer NEEDS_MAINTENANCE and can immediately begin operations again (BUSY). The Maintenance Person becomes available again.

```
Clock =     25.2683
------------SBL----------
TimeStamp:25.412118276949506 Activity/Action: simModel.CastRepaired
TimeStamp:25.899349969330203 Activity/Action: simModel.StationProcessing
TimeStamp:26.47731586992473 Activity/Action: simModel.StationProcessing
TimeStamp:27.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:27.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:27.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:38.35165684469562 Activity/Action: simModel.StationProcessing
---------------------
             MOVER LINE
                     INPUT AREA      STATION            OUTPUT AREA
                                                                 MOVER LINE

           SPITFIRE             CAST 0 : BUSY   [0 ]    {      }       TTB = 9.28   min
           F16                  CAST 1 : BUSY   [0 ]    {      }       TTB = 81.20  min
           CONCORDE             CAST 2 : NMAINT [6 ]    {      }       TTB = 2.66   min
           SPITFIRE             CAST 3 : BUSY   [0 ]    {S     }       TTB = 147.58 min
                                                       {MMMMMMMMMMMMMMMMMMM  } 18


0  {                   }
                     {    S}    CUT  0 : BUSY   [S ]    {      }
                     {     }    CUT  1 : BUSY   [F ]    {F     }
                     {    S}    CUT  2 : BUSY   [C ]    {      }
                                                       {MM                   } 2


0  {                   }
                     {     }    COAT 0 : IDLE   [  ]    {      }
                     {     }    COAT 1 : IDLE   [  ]    {      }
                     {     }    COAT 2 : IDLE   [  ]    {      }
                                                       {                     } 0


0  {                   }
                     {     }    INSP 0 : IDLE   [  ]
                     {     }    INSP 1 : IDLE   [  ]
                     {     }    INSP 2 : IDLE   [  ]


MAINTPER: NOT_AVAILABLE
REPAIRQ:  {                    }
```

```
Clock =     25.4121
------------SBL----------
TimeStamp:25.899349969330203 Activity/Action: simModel.StationProcessing
TimeStamp:26.47731586992473 Activity/Action: simModel.StationProcessing
TimeStamp:27.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:27.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:27.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:28.412118276949506 Activity/Action: simModel.PlaneMoldCast
TimeStamp:38.35165684469562 Activity/Action: simModel.StationProcessing
---------------------
             MOVER LINE
                     INPUT AREA      STATION            OUTPUT AREA
                                                                 MOVER LINE

           SPITFIRE             CAST 0 : BUSY   [0 ]    {      }       TTB = 9.28   min
           F16                  CAST 1 : BUSY   [0 ]    {      }       TTB = 81.20  min
           CONCORDE             CAST 2 : BUSY   [6 ]    {      }       TTB = 20.46  min
           SPITFIRE             CAST 3 : BUSY   [0 ]    {S     }       TTB = 147.58 min
                                                       {MMMMMMMMMMMMMMMMMMM  } 18


0  {                   }
                     {    S}    CUT  0 : BUSY   [S ]    {      }
                     {     }    CUT  1 : BUSY   [F ]    {F     }
                     {    S}    CUT  2 : BUSY   [C ]    {      }
                                                       {MM                   } 2


0  {                   }
                     {     }    COAT 0 : IDLE   [  ]    {      }
                     {     }    COAT 1 : IDLE   [  ]    {      }
                     {     }    COAT 2 : IDLE   [  ]    {      }
                                                       {                     } 0


0  {                   }
                     {     }    INSP 0 : IDLE   [  ]
                     {     }    INSP 1 : IDLE   [  ]
                     {     }    INSP 2 : IDLE   [  ]


MAINTPER: AVAILABLE
REPAIRQ:  {                    }
```

5) Bins Obtained from Input Areas

An IDLE processing station will take a bin from its input area, if available, and begin operations. Here we can see the Cutting station take a F16 bin from the input area, after finishing a Concorde bin.

```
Clock =    24.8500
------------SBL----------
TimeStamp:25.26825018343616 Activity/Action: simModel.StationProcessing
TimeStamp:25.412118276949506 Activity/Action: simModel.CastRepaired
TimeStamp:25.899349969330203 Activity/Action: simModel.StationProcessing
TimeStamp:26.47731586992473 Activity/Action: simModel.StationProcessing
TimeStamp:27.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:27.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:27.0 Activity/Action: simModel.PlaneMoldCast
----------------------
 0  {                    }
                      {    S}    CUT  0 : BUSY    [S ]    {     }
                      {    F}    CUT  1 : BUSY    [C ]    {     }
                      {    S}    CUT  2 : BUSY    [F ]    {     }
                                                             {MM                   } 2
```

```
Clock =    25.2683
------------SBL----------
TimeStamp:25.412118276949506 Activity/Action: simModel.CastRepaired
TimeStamp:25.899349969330203 Activity/Action: simModel.StationProcessing
TimeStamp:26.47731586992473 Activity/Action: simModel.StationProcessing
TimeStamp:27.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:27.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:27.0 Activity/Action: simModel.PlaneMoldCast
----------------------
 0  {                    }
                      {    S}    CUT  0 : BUSY    [S ]    {     }
                      {    F}    CUT  1 : IDLE    [  ]    {     }
                      {    S}    CUT  2 : BUSY    [F ]    {     }
                                                             {MM                   } 2
```

```
Clock =    25.2683
------------SBL----------
TimeStamp:25.412118276949506 Activity/Action: simModel.CastRepaired
TimeStamp:25.899349969330203 Activity/Action: simModel.StationProcessing
TimeStamp:26.47731586992473 Activity/Action: simModel.StationProcessing
TimeStamp:27.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:27.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:27.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:38.35165684469562 Activity/Action: simModel.StationProcessing
----------------------
 0  {                    }
                      {    S}    CUT  0 : BUSY    [S ]    {     }
                      {     }    CUT  1 : BUSY    [F ]    {     }
                      {    S}    CUT  2 : BUSY    [F ]    {     }
                                                             {MM                   } 2
```

6) Cutting/Grinding Stations Process Bins

Here we can see three instances of the StationProcessing activity corresponding to the three cutting stations currently processing a bin.

```
Clock =    25.2683
------------SBL----------
TimeStamp:25.412118276949506 Activity/Action: simModel.CastRepaired
TimeStamp:25.899349969330203 Activity/Action: simModel.StationProcessing
TimeStamp:26.47731586992473 Activity/Action: simModel.StationProcessing
TimeStamp:27.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:27.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:27.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:38.35165684469562 Activity/Action: simModel.StationProcessing
----------------------
             MOVER LINE
                     INPUT AREA      STATION           OUTPUT AREA
                                                                MOVER LINE

           SPITFIRE             CAST 0 : BUSY    [0 ]    {     }       TTB = 9.28   min
           F16                  CAST 1 : BUSY    [0 ]    {     }       TTB = 81.20  min
           CONCORDE             CAST 2 : NMAINT  [6 ]    {     }       TTB = 2.66   min
           SPITFIRE             CAST 3 : BUSY    [0 ]    {S    }       TTB = 147.58 min
                                                            {MMMMMMMMMMMMMMMMMMM  } 18


0  {                     }
                     {    S}    CUT  0 : BUSY    [S ]    {     }
                     {     }    CUT  1 : BUSY    [F ]    {F    }
                     {    S}    CUT  2 : BUSY    [C ]    {     }
                                                            {MM                   } 2


0  {                     }
                     {     }    COAT 0 : IDLE    [  ]    {     }
                     {     }    COAT 1 : IDLE    [  ]    {     }
                     {     }    COAT 2 : IDLE    [  ]    {     }
                                                            {                     } 0


0  {                     }
                     {     }    INSP 0 : IDLE    [  ]
                     {     }    INSP 1 : IDLE    [  ]
                     {     }    INSP 2 : IDLE    [  ]


MAINTPER: NOT_AVAILABLE
REPAIRQ:  {                    }
```

7) Coating Stations Process Bins

In this case we can see two instance of StationProcessing activity corresponding to the two Coating stations currently processing a bin (BUSY). When the station has completed its operations the StationProcessing activity ends, and the station returns to IDLE status.

```
Clock =    26.9073
------------SBL----------
TimeStamp:27.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:27.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:27.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:28.412118276949506 Activity/Action: simModel.PlaneMoldCast
TimeStamp:38.35165684469562 Activity/Action: simModel.StationProcessing
TimeStamp:38.54618186605041 Activity/Action: simModel.StationProcessing
TimeStamp:38.90731586992473 Activity/Action: simModel.StationProcessing
TimeStamp:38.90731586992473 Activity/Action: simModel.StationProcessing
TimeStamp:39.20266788409616 Activity/Action: simModel.StationProcessing
----------------------
             MOVER LINE
                    INPUT AREA      STATION            OUTPUT AREA
                                                               MOVER LINE

            SPITFIRE             CAST 0 : BUSY   [0 ]   {     }       TTB = 9.28   min
            F16                  CAST 1 : BUSY   [0 ]   {     }       TTB = 81.20  min
            CONCORDE             CAST 2 : BUSY   [6 ]   {     }       TTB = 20.46  min
            SPITFIRE             CAST 3 : BUSY   [0 ]   {S    }       TTB = 147.58 min
                                                          {MMMMMMMMMMMMMMMMMMM  } 18


0  {                 }
                    {     }      CUT  0 : BUSY   [S ]   {     }
                    {     }      CUT  1 : BUSY   [F ]   {     }
                    {     }      CUT  2 : BUSY   [S ]   {     }
                                                          {M                    } 1


0  {                 }
                    {     }      COAT 0 : BUSY   [F ]   {     }
                    {     }      COAT 1 : BUSY   [C ]   {     }
                    {     }      COAT 2 : IDLE   [  ]   {     }
                                                          {M                    } 1


0  {                 }
                    {     }      INSP 0 : IDLE   [  ]
                    {     }      INSP 1 : IDLE   [  ]
                    {     }      INSP 2 : IDLE   [  ]


MAINTPER:  AVAILABLE
REPAIRQ:   {                    }
```

```
Clock =    38.9073
------------SBL----------
TimeStamp:38.90731586992473 Activity/Action: simModel.StationProcessing
TimeStamp:39.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:39.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:39.20266788409616 Activity/Action: simModel.StationProcessing
TimeStamp:40.412118276949506 Activity/Action: simModel.PlaneMoldCast
TimeStamp:42.44228292368611 Activity/Action: simModel.CastRepaired
TimeStamp:50.43427638423466 Activity/Action: simModel.StationProcessing
TimeStamp:51.082379179954785 Activity/Action: simModel.StationProcessing
----------------------
             MOVER LINE
                    INPUT AREA      STATION            OUTPUT AREA
                                                               MOVER LINE

            SPITFIRE             CAST 0 : NMAINT [18]   {     }       TTB = 0.28   min
            F16                  CAST 1 : BUSY   [0 ]   {     }       TTB = 69.20  min
            CONCORDE             CAST 2 : BUSY   [6 ]   {     }       TTB = 8.46   min
            SPITFIRE             CAST 3 : BUSY   [0 ]   {S    }       TTB = 135.58 min
                                                          {MMMMMMMMMMMMMMMMMM   } 17


0  {                 }
                    {     }      CUT  0 : BUSY   [F ]   {S    }
                    {     }      CUT  1 : BUSY   [C ]   {F    }
                    {    S}      CUT  2 : BUSY   [S ]   {     }
                                                          {MM                   } 2


0  {                 }
                    {     }      COAT 0 : IDLE   [  ]   {F    }
                    {     }      COAT 1 : BUSY   [C ]   {     }
                    {     }      COAT 2 : IDLE   [  ]   {     }
                                                          {M                    } 1
```

8) Inspection/Packing Stations Process Bins

Again, we see three instances of the StationProcessing activity, corresponding to the three Inspection/Packing stations currently processing a bin (BUSY).

```
Clock =    39.3173
------------SBL----------
TimeStamp:39.63266788409616 Activity/Action: simModel.MoveBins
TimeStamp:40.412118276949506 Activity/Action: simModel.PlaneMoldCast
TimeStamp:42.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:42.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:42.44228292368611 Activity/Action: simModel.CastRepaired
TimeStamp:46.773279428699254 Activity/Action: simModel.StationProcessing
TimeStamp:46.942665706520074 Activity/Action: simModel.StationProcessing
TimeStamp:47.566746521069916 Activity/Action: simModel.StationProcessing
TimeStamp:50.43427638423466 Activity/Action: simModel.StationProcessing
TimeStamp:50.46121834001865 Activity/Action: simModel.StationProcessing
TimeStamp:51.082379179954785 Activity/Action: simModel.StationProcessing
----------------------
             MOVER LINE
                     INPUT AREA      STATION            OUTPUT AREA
                                                                 MOVER LINE

           SPITFIRE            CAST 0 : NMAINT [18]    {     }       TTB = 0.28   min
           F16                 CAST 1 : BUSY   [6 ]    {     }       TTB = 66.20  min
           CONCORDE            CAST 2 : BUSY   [6 ]    {     }       TTB = 8.46   min
           SPITFIRE            CAST 3 : BUSY   [6 ]    {S    }       TTB = 132.58 min
                                                          {MMMMMMMMMMMMMMMMMMM   } 18


0  {                    }
                     {     }   CUT  0 : BUSY   [F ]    {     }
                     {     }   CUT  1 : BUSY   [C ]    {     }
                     {     }   CUT  2 : BUSY   [S ]    {     }
                                                          {M                     } 1


0  {                    }
                     {     }   COAT 0 : IDLE   [  ]    {     }
                     {     }   COAT 1 : IDLE   [  ]    {     }
                     {     }   COAT 2 : IDLE   [  ]    {     }
                                                          {                      } 0


0  {                    }
                     {     }   INSP 0 : BUSY   [S ]
                     {     }   INSP 1 : BUSY   [F ]
                     {     }   INSP 2 : BUSY   [C ]


MAINTPER: NOT_AVAILABLE
REPAIRQ:  {                    }
```

9) Processed Bins to Output Areas

Once a processing station has finished processing a bin its status changes from BUSY to IDLE, and the corresponding StationProcessing activity ends. Subsequently we can see that the Concord bin that was being processed is placed in the output area.

```
Clock =    24.8500
------------SBL----------
TimeStamp:25.26825018343616 Activity/Action: simModel.StationProcessing
TimeStamp:25.412118276949506 Activity/Action: simModel.CastRepaired
TimeStamp:25.899349969330203 Activity/Action: simModel.StationProcessing
TimeStamp:26.47731586992473 Activity/Action: simModel.StationProcessing
TimeStamp:27.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:27.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:27.0 Activity/Action: simModel.PlaneMoldCast
----------------------
0  {                    }
                     {    S}   CUT  0 : BUSY   [S ]    {     }
                     {    F}   CUT  1 : BUSY   [C ]    {     }
                     {    S}   CUT  2 : BUSY   [F ]    {     }
                                                    {MM                 } 2
```

```
Clock =    25.2683
------------SBL----------
TimeStamp:25.412118276949506 Activity/Action: simModel.CastRepaired
TimeStamp:25.899349969330203 Activity/Action: simModel.StationProcessing
TimeStamp:26.47731586992473 Activity/Action: simModel.StationProcessing
TimeStamp:27.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:27.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:27.0 Activity/Action: simModel.PlaneMoldCast
----------------------
0  {                    }
                     {    S}   CUT  0 : BUSY   [S ]    {     }
                     {    F}   CUT  1 : IDLE   [  ]    {     }
                     {    S}   CUT  2 : BUSY   [F ]    {     }
                                                    {MM                 } 2
```

```
Clock =    25.2683
------------SBL----------
TimeStamp:25.412118276949506 Activity/Action: simModel.CastRepaired
TimeStamp:25.899349969330203 Activity/Action: simModel.StationProcessing
TimeStamp:26.47731586992473 Activity/Action: simModel.StationProcessing
TimeStamp:27.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:27.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:27.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:38.35165684469562 Activity/Action: simModel.StationProcessing
----------------------
0  {                    }
                     {    S}   CUT  0 : BUSY   [S ]    {     }
                     {     }   CUT  1 : BUSY   [F ]    {C    }
                     {    S}   CUT  2 : BUSY   [F ]    {     }
                                                    {MM                 } 2
```

10) Stations Blocked

In this frame, several of the output areas for the casting stations have reached capacity (5), because there are no movers to empty the output areas. So when a instance of PlaneMoldCast causes a bin to be filled (24), the casting station is not able to output the bin. The station retains the full bin (24), and is forced into IDLE status since it is unable to proceed with its operations.

```
Clock =    130.9864
------------SBL----------
TimeStamp:131.8685936449722 Activity/Action: simModel.PlaneMoldCast
TimeStamp:132.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:132.79964783553066 Activity/Action: simModel.PlaneMoldCast
TimeStamp:133.86005365874632 Activity/Action: simModel.PlaneMoldCast
TimeStamp:134.23127578559607 Activity/Action: simModel.StationProcessing
TimeStamp:134.85629011918434 Activity/Action: simModel.StationProcessing
----------------------
             MOVER LINE
                     INPUT AREA      STATION            OUTPUT AREA
                                                                 MOVER LINE

           SPITFIRE             CAST 0 : BUSY    [12]    {SSSS }       TTB = 49.23  min
           F16                  CAST 1 : BUSY    [6 ]    {FFFFF}       TTB = 39.25  min
           CONCORDE             CAST 2 : BUSY    [18]    {CCCCC}       TTB = 23.49  min
           SPITFIRE             CAST 3 : BUSY    [18]    {SSSSS}       TTB = 42.58  min
                                                            {                    } 0


0  {                    }
                     {     }    CUT  0 : BUSY    [F ]    {     }
                     {     }    CUT  1 : IDLE    [  ]    {S    }
                     {     }    CUT  2 : BUSY    [S ]    {     }
                                                            {M                   } 1


0  {                    }
                     {     }    COAT 0 : IDLE    [  ]    {     }
                     {     }    COAT 1 : IDLE    [  ]    {     }
                     {     }    COAT 2 : IDLE    [  ]    {     }
                                                            {                    } 0


0  {                    }
                     {     }    INSP 0 : IDLE    [  ]
                     {     }    INSP 1 : IDLE    [  ]
                     {     }    INSP 2 : IDLE    [  ]


MAINTPER: AVAILABLE
REPAIRQ:  {                  }
```

```
Clock =    131.8686
------------SBL----------
TimeStamp:132.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:132.79964783553066 Activity/Action: simModel.PlaneMoldCast
TimeStamp:133.86005365874632 Activity/Action: simModel.PlaneMoldCast
TimeStamp:134.23127578559607 Activity/Action: simModel.StationProcessing
TimeStamp:134.85629011918434 Activity/Action: simModel.StationProcessing
----------------------
             MOVER LINE
                     INPUT AREA      STATION            OUTPUT AREA
                                                                 MOVER LINE

           SPITFIRE             CAST 0 : BUSY    [12]    {SSSS }       TTB = 49.23  min
           F16                  CAST 1 : BUSY    [6 ]    {FFFFF}       TTB = 39.25  min
           CONCORDE             CAST 2 : IDLE    [24]    {CCCCC}       TTB = 20.49  min
           SPITFIRE             CAST 3 : BUSY    [18]    {SSSSS}       TTB = 42.58  min
                                                            {                    } 0
```

11) Movers Circulate

Below we can see the movers waiting at several input and output areas, the movers travel between lines in the order that corresponds to their circulation path.

```
Clock =   116.7733
------------SBL----------
TimeStamp:116.86859364497221 Activity/Action: simModel.PlaneMoldCast
TimeStamp:117.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:117.79964783553066 Activity/Action: simModel.PlaneMoldCast
TimeStamp:118.86005365874634 Activity/Action: simModel.PlaneMoldCast
TimeStamp:123.4351586050923 Activity/Action: simModel.StationProcessing
TimeStamp:125.05684977557954 Activity/Action: simModel.StationProcessing
TimeStamp:128.36327303257997 Activity/Action: simModel.StationProcessing
TimeStamp:128.36327303257997 Activity/Action: simModel.StationProcessing
TimeStamp:129.00155388686554 Activity/Action: simModel.StationProcessing
----------------------
             MOVER LINE
                     INPUT AREA      STATION            OUTPUT AREA
                                                                 MOVER LINE

           SPITFIRE            CAST 0 : BUSY    [6 ]    {     }       TTB = 64.23  min
           F16                 CAST 1 : BUSY    [0 ]    {     }       TTB = 54.25  min
           CONCORDE            CAST 2 : BUSY    [12]    {     }       TTB = 38.49  min
           SPITFIRE            CAST 3 : BUSY    [12]    {     }       TTB = 57.58  min
                                                          {MMMMMMMMMMMMMMMMM    } 16

0  {                      }
                     {    S}   CUT  0 : BUSY    [S ]    {     }
                     {    F}   CUT  1 : BUSY    [C ]    {     }
                     {    S}   CUT  2 : BUSY    [S ]    {     }
                                                          {MM                   } 2

0  {                      }
                     {     }   COAT 0 : BUSY    [F ]    {     }
                     {     }   COAT 1 : BUSY    [C ]    {     }
                     {     }   COAT 2 : IDLE    [  ]    {     }
                                                          {M                    } 1

1  {                     M}
                     {     }   INSP 0 : IDLE    [  ]
                     {     }   INSP 1 : IDLE    [  ]
                     {     }   INSP 2 : IDLE    [  ]


MAINTPER: AVAILABLE
REPAIRQ:  {                    }
```

12) Movers Wait at Input Areas

If a mover arrives (after travel time) at an input area that is completely full, they are unable to drop off the bins they are moving (MoveBins activity), and they end up waiting in line at the input area until space becomes available.

```
Clock =    482.9331
------------SBL----------
TimeStamp:482.9835903461011 Activity/Action: simModel.MoveBins
TimeStamp:485.07140050523526 Activity/Action: simModel.StationProcessing
TimeStamp:486.006104586874 Activity/Action: simModel.StationProcessing
TimeStamp:488.0816359842243 Activity/Action: simModel.StationProcessing
TimeStamp:489.56724291512967 Activity/Action: simModel.StationProcessing
----------------------
             MOVER LINE
                     INPUT AREA      STATION             OUTPUT AREA
                                                                  MOVER LINE

           SPITFIRE              CAST 0 : IDLE    [18]    {      }       TTB = 54.16  min
           F16                   CAST 1 : IDLE    [0 ]    {      }       TTB = 46.49  min
           CONCORDE              CAST 2 : IDLE    [0 ]    {      }       TTB = 27.13  min
           SPITFIRE              CAST 3 : IDLE    [6 ]    {      }       TTB = 100.48 min
                                                            {MMMMMMMMMMMMM        } 12


0  {                        }
                     {FSFFS}    CUT  0 : BUSY    [S ]    {      }
                     {CFCCF}    CUT  1 : BUSY    [C ]    {      }
                     {SCSSS}    CUT  2 : BUSY    [S ]    {      }
                                                            {MMMMMM               } 6


0  {                        }
                     {      }    COAT 0 : BUSY    [F ]    {      }
                     {      }    COAT 1 : IDLE    [  ]    {      }
                     {      }    COAT 2 : IDLE    [  ]    {      }
                                                            {M                    } 1


0  {                        }
                     {      }    INSP 0 : IDLE    [  ]
                     {      }    INSP 1 : IDLE    [  ]
                     {      }    INSP 2 : IDLE    [  ]


MAINTAINER: AVAILABLE
REPAIRQ:  {                    }
```

```
Clock =    482.9836
------------SBL----------
TimeStamp:485.07140050523526 Activity/Action: simModel.StationProcessing
TimeStamp:486.006104586874 Activity/Action: simModel.StationProcessing
TimeStamp:488.0816359842243 Activity/Action: simModel.StationProcessing
TimeStamp:489.56724291512967 Activity/Action: simModel.StationProcessing
----------------------
             MOVER LINE
                     INPUT AREA      STATION             OUTPUT AREA
                                                                  MOVER LINE

           SPITFIRE              CAST 0 : IDLE    [18]    {      }       TTB = 54.16  min
           F16                   CAST 1 : IDLE    [0 ]    {      }       TTB = 46.49  min
           CONCORDE              CAST 2 : IDLE    [0 ]    {      }       TTB = 27.13  min
           SPITFIRE              CAST 3 : IDLE    [6 ]    {      }       TTB = 100.48 min
                                                            {MMMMMMMMMMMMM        } 12

1  {                       M}
                     {FSFFS}    CUT  0 : BUSY    [S ]    {      }
                     {CFCCF}    CUT  1 : BUSY    [C ]    {      }
                     {SCSSS}    CUT  2 : BUSY    [S ]    {      }
                                                            {MMMMMM               } 6
```

13) Movers Wait at Output Areas

After dropping off bins at an input area, movers go to the corresponding output area. If not bins are available for pick up, they will wait in line at the output area until bins become available.

```
Clock =    12.8500
------------SBL----------
TimeStamp:15.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:15.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:15.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:15.0 Activity/Action: simModel.PlaneMoldCast
----------------------
             MOVER LINE
                     INPUT AREA      STATION           OUTPUT AREA
                                                                MOVER LINE

           SPITFIRE            CAST 0 : BUSY   [0 ]    {     }       TTB = 21.28  min
           F16                 CAST 1 : BUSY   [0 ]    {     }       TTB = 93.20  min
           CONCORDE            CAST 2 : BUSY   [0 ]    {     }       TTB = 5.66   min
           SPITFIRE            CAST 3 : BUSY   [0 ]    {S    }       TTB = 159.58 min
                                                          {MMMMMMMMMMMMMMMMMMMM } 19

1  {                     M}
                     {     }   CUT  0 : IDLE   [  ]    {     }
                     {     }   CUT  1 : IDLE   [  ]    {     }
                     {     }   CUT  2 : IDLE   [  ]    {     }
                                                          {                    } 0

0  {                     }
                     {     }   COAT 0 : IDLE   [  ]    {     }
                     {     }   COAT 1 : IDLE   [  ]    {     }
                     {     }   COAT 2 : IDLE   [  ]    {     }
                                                          {                    } 0

0  {                     }
                     {     }   INSP 0 : IDLE   [  ]
                     {     }   INSP 1 : IDLE   [  ]
                     {     }   INSP 2 : IDLE   [  ]

MAINTPER: AVAILABLE
REPAIRQ:  {                    }
```

```
Clock =    12.8500
------------SBL----------
TimeStamp:15.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:15.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:15.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:15.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:25.26825018343616 Activity/Action: simModel.StationProcessing
TimeStamp:25.899349969330203 Activity/Action: simModel.StationProcessing
TimeStamp:26.47731586992473 Activity/Action: simModel.StationProcessing
----------------------
             MOVER LINE
                     INPUT AREA      STATION           OUTPUT AREA
                                                                MOVER LINE

           SPITFIRE            CAST 0 : BUSY   [0 ]    {     }       TTB = 21.28  min
           F16                 CAST 1 : BUSY   [0 ]    {     }       TTB = 93.20  min
           CONCORDE            CAST 2 : BUSY   [0 ]    {     }       TTB = 5.66   min
           SPITFIRE            CAST 3 : BUSY   [0 ]    {S    }       TTB = 159.58 min
                                                          {MMMMMMMMMMMMMMMMMMMM } 19

0  {                     }
                     {     }   CUT  0 : BUSY   [S ]    {     }
                     {     }   CUT  1 : BUSY   [C ]    {     }
                     {     }   CUT  2 : BUSY   [F ]    {     }
                                                          {M                   } 1
```

14) Bins Distributed Evenly to Input Areas

Here we can see a mover at the input area of the the Cutting stations, they distribute 1 bin to each of the cutting stations from the 3 in their trolley. The mover themselves advance to the output area.

```
Clock =    24.8500
------------SBL----------
TimeStamp:25.26825018343616 Activity/Action: simModel.StationProcessing
TimeStamp:25.412118276949506 Activity/Action: simModel.CastRepaired
TimeStamp:25.899349969330203 Activity/Action: simModel.StationProcessing
TimeStamp:26.47731586992473 Activity/Action: simModel.StationProcessing
TimeStamp:27.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:27.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:27.0 Activity/Action: simModel.PlaneMoldCast
----------------------
             MOVER LINE
                     INPUT AREA      STATION           OUTPUT AREA
                                                                MOVER LINE

           SPITFIRE             CAST 0 : BUSY   [0 ]   {     }       TTB = 9.28   min
           F16                  CAST 1 : BUSY   [0 ]   {     }       TTB = 81.20  min
           CONCORDE             CAST 2 : NMAINT [6 ]   {     }       TTB = 2.66   min
           SPITFIRE             CAST 3 : BUSY   [0 ]   {S    }       TTB = 147.58 min
                                                          {MMMMMMMMMMMMMMMMMM  } 18

1  {                      M}
                     {     }    CUT  0 : BUSY   [S ]   {     }
                     {     }    CUT  1 : BUSY   [F ]   {     }
                     {     }    CUT  2 : BUSY   [C ]   {     }
                                                          {M                   } 1

0  {                      }
                     {     }    COAT 0 : IDLE   [  ]   {     }
                     {     }    COAT 1 : IDLE   [  ]   {     }
                     {     }    COAT 2 : IDLE   [  ]   {     }
                                                          {                    } 0

0  {                      }
                     {     }    INSP 0 : IDLE   [  ]
                     {     }    INSP 1 : IDLE   [  ]
                     {     }    INSP 2 : IDLE   [  ]

MAINTPER: NOT_AVAILABLE
REPAIRQ:   {                 }
```

```
Clock =    24.8500
------------SBL----------
TimeStamp:25.26825018343616 Activity/Action: simModel.StationProcessing
TimeStamp:25.412118276949506 Activity/Action: simModel.CastRepaired
TimeStamp:25.899349969330203 Activity/Action: simModel.StationProcessing
TimeStamp:26.47731586992473 Activity/Action: simModel.StationProcessing
TimeStamp:27.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:27.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:27.0 Activity/Action: simModel.PlaneMoldCast
----------------------
             MOVER LINE
                     INPUT AREA      STATION           OUTPUT AREA
                                                                MOVER LINE

           SPITFIRE             CAST 0 : BUSY   [0 ]   {     }       TTB = 9.28   min
           F16                  CAST 1 : BUSY   [0 ]   {     }       TTB = 81.20  min
           CONCORDE             CAST 2 : NMAINT [6 ]   {     }       TTB = 2.66   min
           SPITFIRE             CAST 3 : BUSY   [0 ]   {S    }       TTB = 147.58 min
                                                          {MMMMMMMMMMMMMMMMMM  } 18

0  {                      }
                     {    S}    CUT  0 : BUSY   [S ]   {     }
                     {    F}    CUT  1 : BUSY   [F ]   {     }
                     {    S}    CUT  2 : BUSY   [C ]   {     }
                                                          {MM                  } 2
```

15) Bins Collected from Output Areas

There are two bins available in the output area of the Casting stations, once a third bin is produced by the casting stations a MoveBins activity can be initialized and we see the bins disappear along with a mover. The mover has picked up the three bins from the output areas.

```
Clock =    12.0000
------------SBL----------
TimeStamp:12.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:12.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:15.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:15.0 Activity/Action: simModel.PlaneMoldCast
----------------------
             MOVER LINE
                     INPUT AREA      STATION            OUTPUT AREA
                                                                 MOVER LINE

           SPITFIRE             CAST 0 : BUSY   [0 ]    {S     }       TTB = 21.28  min
           F16                  CAST 1 : BUSY   [0 ]    {F     }       TTB = 93.20  min
           CONCORDE             CAST 2 : BUSY   [18]    {      }       TTB = 8.66   min
           SPITFIRE             CAST 3 : BUSY   [18]    {      }       TTB = 162.58 min
                                                           {MMMMMMMMMMMMMMMMMMMM} 20


0  {                 }
                     {     }    CUT  0 : IDLE   [  ]    {      }
                     {     }    CUT  1 : IDLE   [  ]    {      }
                     {     }    CUT  2 : IDLE   [  ]    {      }
                                                           {                    } 0


0  {                 }
                     {     }    COAT 0 : IDLE   [  ]    {      }
                     {     }    COAT 1 : IDLE   [  ]    {      }
                     {     }    COAT 2 : IDLE   [  ]    {      }
                                                           {                    } 0


0  {                 }
                     {     }    INSP 0 : IDLE   [  ]
                     {     }    INSP 1 : IDLE   [  ]
                     {     }    INSP 2 : IDLE   [  ]


MAINTPER: AVAILABLE
REPAIRQ:  {                    }
```

```
Clock =    12.0000
------------SBL----------
TimeStamp:12.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:12.85 Activity/Action: simModel.MoveBins
TimeStamp:15.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:15.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:15.0 Activity/Action: simModel.PlaneMoldCast
----------------------
             MOVER LINE
                     INPUT AREA      STATION            OUTPUT AREA
                                                                 MOVER LINE

           SPITFIRE             CAST 0 : BUSY   [0 ]    {      }       TTB = 21.28  min
           F16                  CAST 1 : BUSY   [0 ]    {      }       TTB = 93.20  min
           CONCORDE             CAST 2 : BUSY   [0 ]    {      }       TTB = 5.66   min
           SPITFIRE             CAST 3 : BUSY   [18]    {      }       TTB = 162.58 min
                                                           {MMMMMMMMMMMMMMMMMMM } 19
```

16) SpitFire Skip Coating Stations

In this frame we see that there are three Coating stations, one processing a F16 bin, one processing a Concord bin, and the third one is IDLE. Yet, there is a mover in the waiting at the output area. The only way this is possible is if the mover retained a SpitFire bin with them instead of dropping it off at the Coating stations.

```
Clock =    34.4121
------------SBL----------
TimeStamp:36.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:36.0 Activity/Action: simModel.PlaneMoldCast
TimeStamp:37.412118276949506 Activity/Action: simModel.PlaneMoldCast
TimeStamp:38.35165684469562 Activity/Action: simModel.StationProcessing
TimeStamp:38.54618186605041 Activity/Action: simModel.StationProcessing
TimeStamp:38.90731586992473 Activity/Action: simModel.StationProcessing
TimeStamp:38.90731586992473 Activity/Action: simModel.StationProcessing
TimeStamp:39.20266788409616 Activity/Action: simModel.StationProcessing
TimeStamp:42.44228292368611 Activity/Action: simModel.CastRepaired
----------------------
             MOVER LINE
                     INPUT AREA      STATION           OUTPUT AREA
                                                                MOVER LINE

           SPITFIRE              CAST 0 : NMAINT [18]    {     }       TTB = 0.28   min
           F16                   CAST 1 : BUSY   [18]    {     }       TTB = 72.20  min
           CONCORDE              CAST 2 : BUSY   [0 ]    {C    }       TTB = 11.46  min
           SPITFIRE              CAST 3 : BUSY   [18]    {S    }       TTB = 138.58 min
                                                            {MMMMMMMMMMMMMMMMMMM   } 18


0  {                     }
                     {     }    CUT  0 : BUSY   [S ]    {     }
                     {     }    CUT  1 : BUSY   [F ]    {     }
                     {     }    CUT  2 : BUSY   [S ]    {     }
                                                            {M                    } 1


0  {                     }
                     {     }    COAT 0 : BUSY   [F ]    {     }
                     {     }    COAT 1 : BUSY   [C ]    {     }
                     {     }    COAT 2 : IDLE   [  ]    {     }
                                                            {M                    } 1


0  {                     }
                     {     }    INSP 0 : IDLE   [  ]
                     {     }    INSP 1 : IDLE   [  ]
                     {     }    INSP 2 : IDLE   [  ]


MAINTPER: NOT_AVAILABLE
REPAIRQ:  {                     }
```

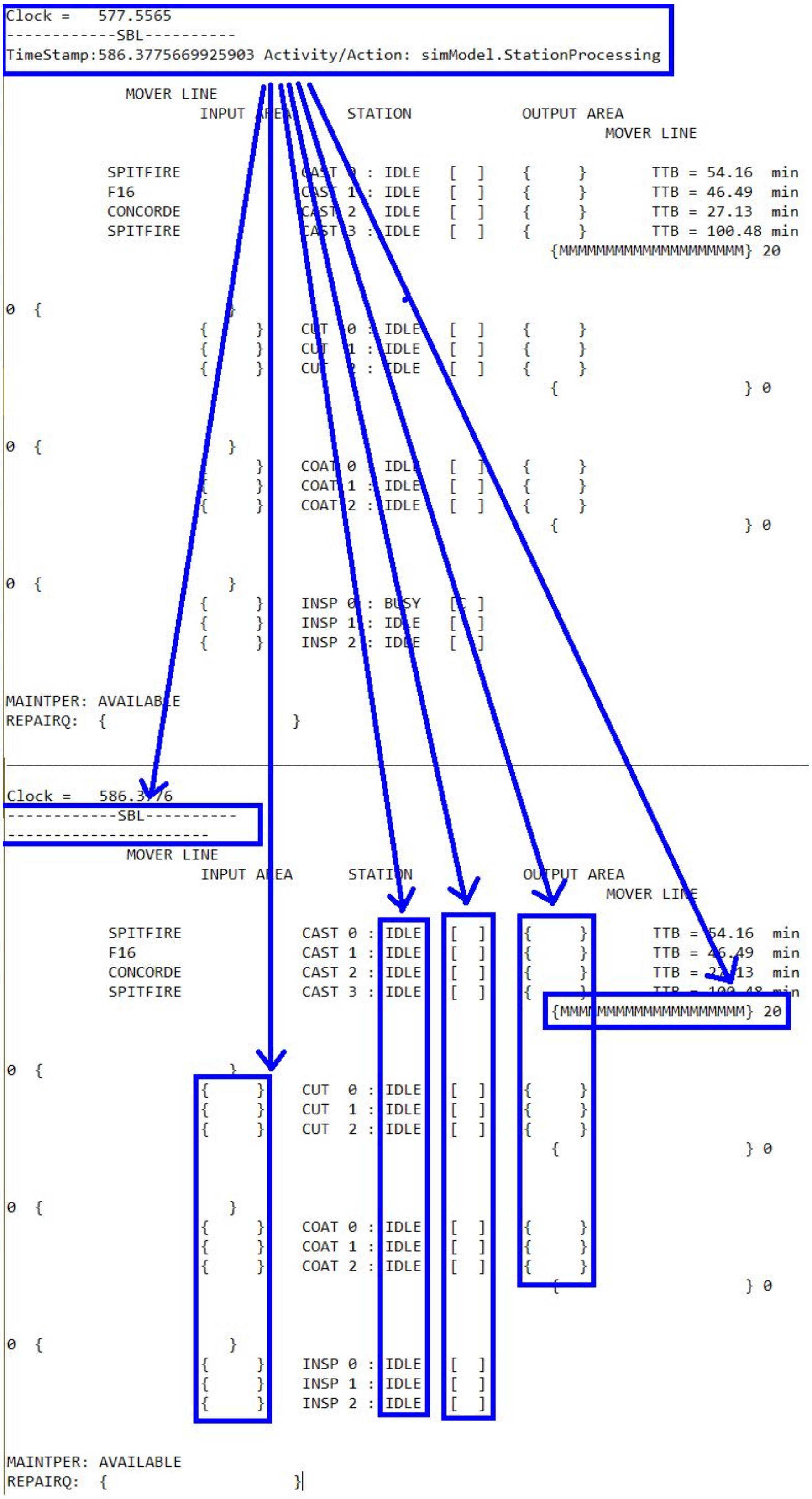
17) End of Workday - Casting Stations Stop Production

Here we see that last instance of PlaneMoldCast activity, just before T=480 (the end of the work day). Only the one station involved in the PlaneMoldCast activity is BUSY. Although there are other Casting stations able to do work, they do not initiate any operations after t=480 and remain IDLE.

```
Clock =   479.7906
------------SBL----------
TimeStamp:479.79911232468714 Activity/Action: simModel.PlaneMoldCast
TimeStamp:482.1335903461011 Activity/Action: simModel.StationProcessing
TimeStamp:482.3118731230425 Activity/Action: simModel.StationProcessing
TimeStamp:482.93308476233653 Activity/Action: simModel.StationProcessing
TimeStamp:485.07140050523526 Activity/Action: simModel.StationProcessing
TimeStamp:486.006104586874 Activity/Action: simModel.StationProcessing
TimeStamp:488.0816359842243 Activity/Action: simModel.StationProcessing
TimeStamp:489.56724291512967 Activity/Action: simModel.StationProcessing
--------------------
             MOVER LINE
                     INPUT AREA      STATION           OUTPUT AREA
                                                                MOVER LINE

           SPITFIRE              CAST 0 : BUSY  [12]   {     }       TTB = 57.16  min
           F16                   CAST 1 : IDLE  [0 ]   {     }       TTB = 46.49  min
           CONCORDE              CAST 2 : IDLE  [0 ]   {C    }       TTB = 27.13  min
           SPITFIRE              CAST 3 : IDLE  [6 ]   {     }       TTB = 100.48 min
                                                          {MMMMMMMMMMMMMM       } 13


0  {                  }
                     {FSFFS}    CUT  0 : BUSY   [S ]   {     }
                     {CFCCF}    CUT  1 : BUSY   [C ]   {     }
                     {SCSSS}    CUT  2 : BUSY   [S ]   {     }
                                                          {MMMMMM               } 6


0  {                  }
                     {     }    COAT 0 : BUSY   [F ]   {     }
                     {     }    COAT 1 : IDLE   [  ]   {     }
                     {     }    COAT 2 : IDLE   [  ]   {     }
                                                          {M                    } 1


0  {                  }
                     {     }    INSP 0 : BUSY   [C ]
                     {     }    INSP 1 : BUSY   [F ]
                     {     }    INSP 2 : BUSY   [C ]


MAINTPER: AVAILABLE
REPAIRQ:  {                    }
```

18) End of Simulation - Stations Emptied Out

The production line is kept running at the end of the day until all the stations are cleared. Here we see the last activity, StationProcessing. After which no more activities show up in the SBL, all the input and output areas are empty, and all the stations are IDLE.



```
Clock =    577.5565
------------SBL----------
TimeStamp:586.3775669925903 Activity/Action: simModel.StationProcessing
             MOVER LINE
                     INPUT AREA      STATION           OUTPUT AREA
                                                               MOVER LINE

           SPITFIRE                  CAST 0 : IDLE   [  ]   {     }      TTB = 54.16  min
           F16                       CAST 1 : IDLE   [  ]   {     }      TTB = 46.49  min
           CONCORDE                  CAST 2 : IDLE   [  ]   {     }      TTB = 27.13  min
           SPITFIRE                  CAST 3 : IDLE   [  ]   {     }      TTB = 100.48 min
                                                              {MMMMMMMMMMMMMMMMMMMM} 20

0  {                 }
                     {     }     CUT  0 : IDLE   [  ]   {     }
                     {     }     CUT  1 : IDLE   [  ]   {     }
                     {     }     CUT  2 : IDLE   [  ]   {     }
                                                          {                  } 0

0  {                 }
                     {     }     COAT 0 : IDLE   [  ]   {     }
                     {     }     COAT 1 : IDLE   [  ]   {     }
                     {     }     COAT 2 : IDLE   [  ]   {     }
                                                          {                  } 0

0  {                 }
                     {     }     INSP 0 : BUSY   [C ]
                     {     }     INSP 1 : IDLE   [  ]
                     {     }     INSP 2 : IDLE   [  ]

MAINTPER: AVAILABLE
REPAIRQ:  {                    }
------------------------------------------------------------------------------
Clock =    586.3776
------------SBL----------
----------------------
             MOVER LINE
                     INPUT AREA      STATION           OUTPUT AREA
                                                               MOVER LINE

           SPITFIRE                  CAST 0 : IDLE   [  ]   {     }      TTB = 54.16  min
           F16                       CAST 1 : IDLE   [  ]   {     }      TTB = 46.49  min
           CONCORDE                  CAST 2 : IDLE   [  ]   {     }      TTB = 27.13  min
           SPITFIRE                  CAST 3 : IDLE   [  ]   {     }      TTB = 100.48 min
                                                              {MMMMMMMMMMMMMMMMMMMM} 20

0  {                 }
                     {     }     CUT  0 : IDLE   [  ]   {     }
                     {     }     CUT  1 : IDLE   [  ]   {     }
                     {     }     CUT  2 : IDLE   [  ]   {     }
                                                          {                  } 0

0  {                 }
                     {     }     COAT 0 : IDLE   [  ]   {     }
                     {     }     COAT 1 : IDLE   [  ]   {     }
                     {     }     COAT 2 : IDLE   [  ]   {     }
                                                          {                  } 0

0  {                 }
                     {     }     INSP 0 : IDLE   [  ]
                     {     }     INSP 1 : IDLE   [  ]
                     {     }     INSP 2 : IDLE   [  ]

MAINTPER: AVAILABLE
REPAIRQ:  {                    }
```

Report of validation and verification

During our analysis of the output logs we looked for evidence of the validation test cases previously outlined. For all test cases we were able to clearly identify instances of the model performing the expected functions, as illustrated above with the screenshots diagrams.

We concluded that our program is running correctly, and our model reflects the intended behaviours as described in our conceptual model.

Experimentation and Analysis

Experimentation

A number of experimentation programs were created for this project. Review the following Java classes:

1) Experiment:

- Used for generation of trace logs for the purpose of verification and validation, reported in the previous section.
- Used for getting the optimal parameter.

2) ExperimentAnalysis:

Generates a table showing simulation values for one simulation runs for each type of plane using a desired confidence level of 0.9.

Planes	Point estimate(ybar(n))	s(n)	zeta	CI Min	CI Max	|zeta/ybar(n)|
Concorde	2357.960	29310.988	28.427	2329.533	2386.387	0.012
F16	1977.820	30525.058	29.009	1948.811	2006.829	0.015
Spitfire	1570.500	42110.273	34.072	1536.428	1604.572	0.022

3) ExperimentAnalysis2:

This table shows the effect of increasing the number of runs on the confidence interval. The results are shown below using a desired confidence level of 0.9.

Result (Concorde, F16, Spitfire):

n	y(n)			s(n)			zeta(n)		
20	2311.200	2032.300	1561.800	174.611	181.169	195.290	67.515	70.051	75.511
30	2356.267	1997.700	1548.633	167.998	166.019	191.481	52.116	51.502	59.401
40	2361.425	1988.800	1581.000	166.215	169.278	191.516	44.278	45.094	51.018
60	2344.717	1986.183	1584.783	194.830	163.696	195.004	42.031	35.315	42.069
80	2354.488	1981.950	1582.038	178.029	167.315	201.804	33.128	31.134	37.552
100	2357.960	1977.820	1570.500	171.205	174.714	205.208	28.427	29.009	34.072
1000	2355.554	1970.912	1565.885	178.256	179.164	198.363	9.280	9.328	10.327
10000	2358.870	1973.459	1563.411	174.087	176.336	197.887	2.864	2.901	3.255

CI Min			CI Max			zeta(n)/y(n)		
2243.685	1962.249	1486.289	2378.715	2102.351	1637.311	0.029	0.034	0.048
2304.150	1946.198	1489.232	2408.383	2049.202	1608.035	0.022	0.026	0.038
2317.147	1943.706	1529.982	2405.703	2033.894	1632.018	0.019	0.023	0.032
2302.685	1950.869	1542.714	2386.748	2021.498	1626.852	0.018	0.018	0.027
2321.360	1950.816	1544.486	2387.615	2013.084	1619.589	0.014	0.016	0.024
2329.533	1948.811	1536.428	2386.387	2006.829	1604.572	0.012	0.015	0.022
2346.274	1961.584	1555.558	2364.834	1980.240	1576.212	0.004	0.005	0.007
2356.006	1970.558	1560.156	2361.734	1976.360	1566.667	0.001	0.001	0.002

When the number of runs is 20 in ExperimentAnalysis2, the interval half lengths already meet the 10% criterion (that is zeta(n)/y(n) < 0.1).

Output Analysis

The following sample outputs of our Experiment shows how the program is implementing our deterministic algorithm to find the optimal parameters to reach the target production numbers.

```
Simulation 1 with parameters: 1, 1, 1, 20, 20, 20, 20
------------------------------------------------------------
Outputs:
Num F16 produced: 706.9(36.25%)
Num Concorde produced: 702.0(30.00%)
Num Spitfire produced: 701.0(53.92%)
------------------------------------------------------------
   .
   .
   .
Simulation 70 with parameters: 3, 4, 5, 5, 4, 3, 18
------------------------------------------------------------
Outputs:
Num F16 produced: 1988.8(101.99%)
Num Concorde produced: 2361.425(100.92%)
Num Spitfire produced: 1581.0(121.62%)
------------------------------------------------------------

Found optimal parameters!
```

Table of simulation results

The parameter changes by the algorithm are summarized in the table below. In the left most column, we can see the number of each simulation run. The simulation highlighted in yellow indicates the best configuration for the parameters highlighted in red. These milestones reflect key points in our algorithmic approach to finding the optimal configuration for all parameters.

n°	Parameters							Production					
	nCSSpit	nCSF16	nCSCon	nCGS	nCoatS	nInspS	nMoov	F-16		Concorde		Spitfire	
								Number	Evo. in %	Number	Evo. in %	Number	Evo. in %
1	1	1	1	20	20	20	20	706.9	36.25	702.0	30.00	701.0	53.92
2	2	1	1	20	20	20	20	693.35	35.56	687.025	29.36	1384.775	106.52
3	2	2	1	20	20	20	20	1358.125	69.65	670.975	28.67	1378.025	106.00
4	2	3	1	20	20	20	20	2011.6	103.16	671.975	28.72	1370.3	105.41
5	2	3	2	20	20	20	20	1960.65	100.55	1312.15	56.07	1359.05	104.54
6	2	3	3	20	20	20	20	1916.025	98.26	1911.075	81.67	1313.175	101.01
7	2	3	3	20	20	20	20	1916.025	98.26	1911.075	81.67	1313.175	101.01
8	2	4	3	20	20	20	20	2452.8	125.78	1857.675	79.39	1238.35	95.26
9	2	4	3	20	20	20	20	2452.8	125.78	1857.675	79.39	1238.35	95.26
10	3	4	3	20	20	20	20	2350.375	120.53	1746.975	74.66	1785.825	137.37
11	3	4	4	20	20	20	20	2241.275	114.94	2233.0	95.43	1678.825	129.14
12	3	4	5	20	20	20	20	2109.875	108.20	2634.225	112.57	1607.575	123.66
Search of the best value for: numCoattingStations													
13	3	4	5	20	19	20	20	2109.875	108.20	2634.225	112.57	1607.575	123.66
[...]	[...]												
27	3	4	5	20	5	20	20	2109.125	108.16	2636.975	112.69	1605.575	123.51
28	3	4	5	20	4	20	20	2067.15	106.01	2544.425	108.74	1604.9	123.45
29	3	4	5	20	3	20	20	1907.075	97.80	2258.325	96.51	1565.8	120.45
30	3	4	5	20	4	20	20	2067.15	106.01	2544.425	108.74	1604.9	123.45
Search of the best value for: numCuttingGrindingStations													
31	3	4	5	19	4	20	20	2067.025	106.00	2544.35	108.73	1605.1	123.47
[...]	[...]												
44	3	4	5	6	4	20	20	2060.85	105.68	2532.175	108.21	1603.775	123.37
45	3	4	5	5	4	20	20	2006.8	102.91	2408.6	102.93	1586.525	122.04
46	3	4	5	4	4	20	20	1846.15	94.67	2140.8	91.49	1528.75	117.60
47	3	4	5	5	4	20	20	2006.8	102.91	2408.6	102.93	1586.525	122.04
Search of the best value for: numInspectionPackagingStations													
48	3	4	5	5	4	19	20	2006.8	102.91	2408.6	102.93	1586.525	122.04
[...]	[...]												
63	3	4	5	5	4	4	20	2007.575	102.95	2405.925	102.82	1588.425	122.19
64	3	4	5	5	4	3	20	2004.875	102.81	2413.825	103.15	1583.225	121.79
65	3	4	5	5	4	2	20	1758.925	90.20	2033.15	86.89	1463.175	112.55
66	3	4	5	5	4	3	20	2004.875	102.81	2413.825	103.15	1583.225	121.79
Search of the best value for: numMovers													
67	3	4	5	5	4	3	19	1991.225	102.11	2389.55	102.12	1582.325	121.72
68	3	4	5	5	4	3	18	1988.8	101.99	2361.425	100.92	1581.0	121.62
69	3	4	5	5	4	3	17	1964.9	100.76	2337.125	99.88	1586.775	122.06
70	3	4	5	5	4	3	18	1988.8	101.99	2361.425	100.92	1581.0	121.62

Detailed Analysis:

In the following tables, each combination of parameters (2-3-2; 2-3-3; etc...) correspond to the values for numCastingStationSpitfire, numCastingStationF16, and numCastingStationConcorde in this order. The number of planes produced for each type is provided, along with the percent of target production this number corresponds to (100% means that the target production has been reached).

Search of the best value for: numCastingStations										
Each test are realised with the same values for each other parametters.										
Try with:		2	3	2	2	3	3	2	4	3
F-16	Number	1960.65			1916.025			2452.8		
	Evo. in %	100.55			98.26			125.78		
Concorde	Number	1312.15			1911.075			1857.675		
	Evo. in %	56.07			81.67			79.39		
Spitfire	Number	1359.05			1313.175			1238.35		
	Evo. in %	104.54			101.01			95.26		
Try with:		3	4	3	3	4	4	3	4	5
F-16	Number	2350.375			2241.275			2109.875		
	Evo. in %	120.53			114.94			108.20		
Concorde	Number	1746.975			2233.0			2634.225		
	Evo. in %	74.66			95.43			112.57		
Spitfire	Number	1785.825			1678.825			1607.575		
	Evo. in %	137.37			129.14			123.66		

In the table above we can observe the evolution of the production numbers when the values of parameters (numCastingStationsSpitfire, numCastingStationsF16, numCastingStationsConcorde) change according to our algorithm
We can observe that the best combination of parameters that produce a score higher than 100% is (3,4,5) respectively.
We do not need to increase the parameter values further beyond (3,4,5) for (numCastingStationsSpitfire, numCastingStationsF16, numCastingStationsConcorde), as the target production values have been reached for all three types of planes using a minimum optimal number of Casting stations.

Search of the best value for: numCoatingStations						
Each test are realised with the same values for each other parametters.						
Try with:		19		5	4	3
F-16	Number	2109.875	[...]	2109.125	2067.15	1907.075
	Evo. in %	108.20		108.16	106.01	97.80
Concorde	Number	2634.225		2636.975	2544.425	2258.325
	Evo. in %	112.57		112.69	108.74	96.51
Spitfire	Number	1607.575		1605.575	1604.9	1565.8
	Evo. in %	123.66		123.51	123.45	120.45

In the table above we can observe the change in the production numbers when the value of parameter numCoatingStations is decreasing according to our algorithm.
We can observe that the minimum value for the parameter that meets the target production (greater than 100% for all three airplane types) is 4.
The algorithm does need to decrease the parameter value beyond 4 for numCoatingStations, as the target production values have been reached for all three types of planes using a minimum optimal number of Coating stations.

Search of the best value for: numCuttingGrindingStations						
Each test are realised with the same values for each other parametters.						
Try with:		19		6	5	4
F-16	Number	2067.025	[...]	2060.85	2006.8	1846.15
	Evo. in %	106.00		105.68	102.91	94.67
Concorde	Number	2544.35		2532.175	2408.6	2140.8
	Evo. in %	112.57		108.21	102.93	91.49
Spitfire	Number	108.73		1603.775	1586.525	1528.75
	Evo. in %	1605.1		123.37	122.04	117.60

Likewise, In the table above we can observe the change in the production numbers when the value of parameter numCuttingGrindingStations is decreasing according to our algorithm.
We can observe that the minimum value for the parameter that meets the target production (greater than 100% for all three airplane types) is 5.
The algorithm does need to decrease the parameter value beyond 5 for numCuttingGrindingStations, as the target production values have been reached for all three types of planes using a minimum optimal number of Cutting/Grinding stations.

Search of the best value for: numInspectionPackagingStations						
Each test are realised with the same values for each other paramettersˌ						
Try with:		19		4	3	2
F-16	Number	2006.8	[...]	2007.575	2004.875	1758.925
	Evo. in %	102.91		102.95	102.81	90.20
Concorde	Number	2408.6		2405.925	2413.825	2033.15
	Evo. in %	102.93		102.82	103.15	86.89
Spitfire	Number	1586.525		1588.425	1583.225	1463.175
	Evo. in %	122.04		122.19	121.79	112.55

Again, In the table above we can observe the change in the production numbers when the value of parameter numInspectionPackingStations is decreasing according to our algorithm. We can observe that the minimum value for the parameter that meets the target production (greater than 100% for all three airplane types) is 3.
The algorithm does need to decrease the parameter value beyond 3 for numInspectionPackingStations, as the target production values have been reached for all three types of planes using a minimum optimal number of Inspection/Packing stations.

Search of the best value for: numMovers				
Each test are realised with the same values for each other parametters.				
Try with:		19	18	17
F-16	Number	1991.225	1988.8	1964.9
	Evo. in %	102.11	101.99	100.76
Concorde	Number	2389.55	2361.425	2337.125
	Evo. in %	102.12	100.92	99.88
Spitfire	Number	1582.325	1581.0	1586.775
	Evo. in %	121.72	121.62	122.06

Lastly, in the table above we can observe the change in the production numbers when the value of parameter numMovers is decreasing according to our algorithm.
We can observe that the minimum value for the parameter that meets the target production (greater than 100% for all three airplane types) is 18.
The algorithm does need to decrease the parameter value beyond 18 for numMovers, as the target production values have been reached for all three types of planes using a minimum optimal number of Movers.

Conclusions

According to our algorithm and the experiments conducted with our simulation model program, the optimal parameter configuration is as follows:

Parameter	Optimal Value
Movers	18
Casting Stations for producing F-16	4
Casting Stations for producing Concorde	5
Casting Stations for producing Spitfire	3
Cutting/Grinding Station	5
Coating Station	4
Inspection/Packing Station	3

We have found the optimal combinations of machines and personnel that defines a production capacity capable of meeting the increase in demand that management requires.

Case Study

(As provided by the Professor, will not be part of the Final Report)

Case 3 - TOY AIRPLANE MANUFACTURING

Legend - specific details related to:

- toy airplanes
- casting stations
- cutting/grinding stations
- coating stations
- inspection/packing stations
- input/output areas
- movers
- bins
- repair man

A toy company produces three types (Spitfire, F-16, and Concorde) of toy aluminum airplanes in the following daily volumes: Spitfire =1000, F-16 = 1500 and Concorde = 1800. The company expects demand to increase for its products by 30 percent over the next six months and needs to know the total machines and operators that will be required. Planes go through the following operations (note that Spitfire airplanes do not require coating) at 4 different stations.

1. **Casting:** A casting station consists of an aluminum holding furnace and an automated cold-chamber die caster is used to cast a type of airplane. The die caster injects a precise amount of molten aluminum metal from a holding furnace into molds that produce a casting of 6 airplanes. The die caster contains the die to produce one of the airplane types: Spitfire, F-16, and Concorde. Separate machines are used to create castings of different airplane types. Die casters experience regular downtimes which must be repaired. When a machine fails, the molten aluminum is returned to the aluminum furnace. After being repaired the machine restarts a new casting of planes. One maintenance person is always on duty to make rep
2. airs. The airplanes are placed in bins that can hold 4 castings, that is, 24 toy airplanes. These stations are fully automated and require no operator.
3. **Cutting/Grinding:** The airplanes in a casting produce by a die caster must be separated from each other and grinded to remove any defects from the casting and cutting operations. A cutting/grinding station is designed and setup with a workbench, an aluminum laser cutter and a grinder with an

aluminum grinding wheel. The station is operated by one person to 1) separate the 6 planes from a casting and 2) grind defects on each plane created by the casting and cutting. The finished planes are placed in bins that can hold up to 24 individual airplanes.

4. **Coating:** A coating station consists of a workbench and an aluminum coating machine. The coating machine is used to anodize the aluminum toy airplanes and can process up to 24 planes in a single batch. The anodized airplanes are placed into bins that can hold 24 individual airplanes. Only F-16 and Concorde toy airplanes require this operation. The Spitfire planes skip this operation and go directly to the Inspection and Packaging operation.
5. **Inspection and Packaging:** An inspection station consists of an inspection workbench and a packing post. The packing post can hold 3 boxes. Each of the packing boxes holds a different toy airplane type and can hold 48 toy airplanes. Airplanes are inspected for defects. Those that meet inspection are packaged into the appropriate box. Those that do not meet inspection are placed in a reject bin that can hold up to 24 planes.

Figure 1 shows the layout of the manufacturing plant. Space exists in the plant for up to 20 Casting Stations, 20 Cutting/Grinding Stations, 20 Coating Stations, and 20 Inspection/Packaging Stations. Stations have an input area that contains bins of airplanes for processing at the stations and an output area where bins of processed planes are placed (these output bins, when full, are ready to be moved to another station). The Casting Stations do not have an input area and the Inspection/Packaging Stations do not have an output area. The empty bins at the Inspection/Packaging Stations are stacked and moved to the Casting Stations.

The various bins are moved from station to station by moving staff (movers) with the use of a trolley that can hold up to 3 bins. The following table shows the number of bins that can be located at each of the stations.

Station	Input Area Bins	Output Area Bins
Casting Station	N/a	5
Cutting/Grinding Station	5	5
Coating Station	5	5
Inspection/Packaging Station	5	N/A

When the output section of a station becomes full, then the station is considered blocked. It can complete its current operation, but cannot add another bin to its output section until space is made when a mover picks up bins from its output area. A mover circulates through the plant cycling through the following steps:

1. Moving bins from the output areas of the Casting Stations to the input areas of the Cutting/Grinding stations.

2. Moving bins from the output areas of the Cutting/Grinding stations to the input areas of the Coating stations, in the case of the F-16 and Concorde planes. Spitfire planes are moved directly to the input area of the Inspection/Packing Station.
3. Moving bins from the output areas of the Coating Stations to the input areas of the Inspection/Packing Stations. This mover is also responsible for moving empty bins from the Inspection/Packing Station to the Casting Stations.
4. Move empty bins from the Inspection/Packing Stations back to the Casting stations.

Movers pick up full bins from an output area until his/her trolley is full and then distributes them evenly to the input areas. If all input areas are full, then the mover waits until space is available. Only when his/her trolley is empty will the mover start the next step.

Boxes that are full at the Inspection/Packaging Station are replaced with empty boxes. The full boxes are picked up at regular intervals by warehouse personnel such that full boxes never accumulate at the Inspection/Packaging Stations.

The factory operates eight hours a day, five days per week. The factory starts out empty at the beginning of each day and ships all parts produced at the end of the day, thus machines and operators work at the end of the eight hour period until all stations are empty.

Find the total number of machines and personnel needed to meet daily production requirements.

Following is a list of operation times:

	Operation	Operation Time	Station
1	Die casting	3 min (output 6 airplanes) The die caster experiences downtimes every 30 minutes exponentially distributed and takes 8 minutes normally distributed with a standard deviation of 2 minutes to repair. One maintenance person is always on duty to make repairs.	Automated die caster
2a	Cutting	Triangular (0.25, 0.28, 0.35) minutes per airplane	Cutting/Grinding Station
2b	Grinding	Sample times (min per airplane): 0.23, 0.22, 0.26, 0.22, 0.25, 0.23, 0.24, 0.22, 0.21, 0.23, 0.20, 0.23, 0.22, 0.25, 0.23, 0.24, 0.23, 0.25, 0.47, 0.23, 0.25, 0.21, 0.24, 0.22, 0.26, 0.23, 0.25, 0.24, 0.21, 0.24, 0.26	Cutting/Grinding Station
3	Coating	12 min per batch of 24 airplanes	Coating Station
4	Inspection and packaging	Triangular (0.27, 0.30, 0.40) minutes per airplane	Inspection/Packaging Station 88% of planes pass inspection

The following table shows move times between stations

Moving from Output Area to Input Area	Moving Time

Casting Stations to Cutting/Grinding Stations	0.85 minutes
Cutting/Grinding Stations to Coating stations	0.43 minutes
Coating Stations to Inspection/Packaging Stations	0.41 minutes
From Inspection/Packing Stations to the Casting Stations	1.35 minutes

~ End of Case Study ~