IE 327
Facility Design
& Material Handling

Final Presentation

University at Buffalo
Department of Industrial
and Systems Engineering
School of Engineering and Applied Sciences

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Industrial Development Plan

Board to Death - Game Manufacturer

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Presentation Outline

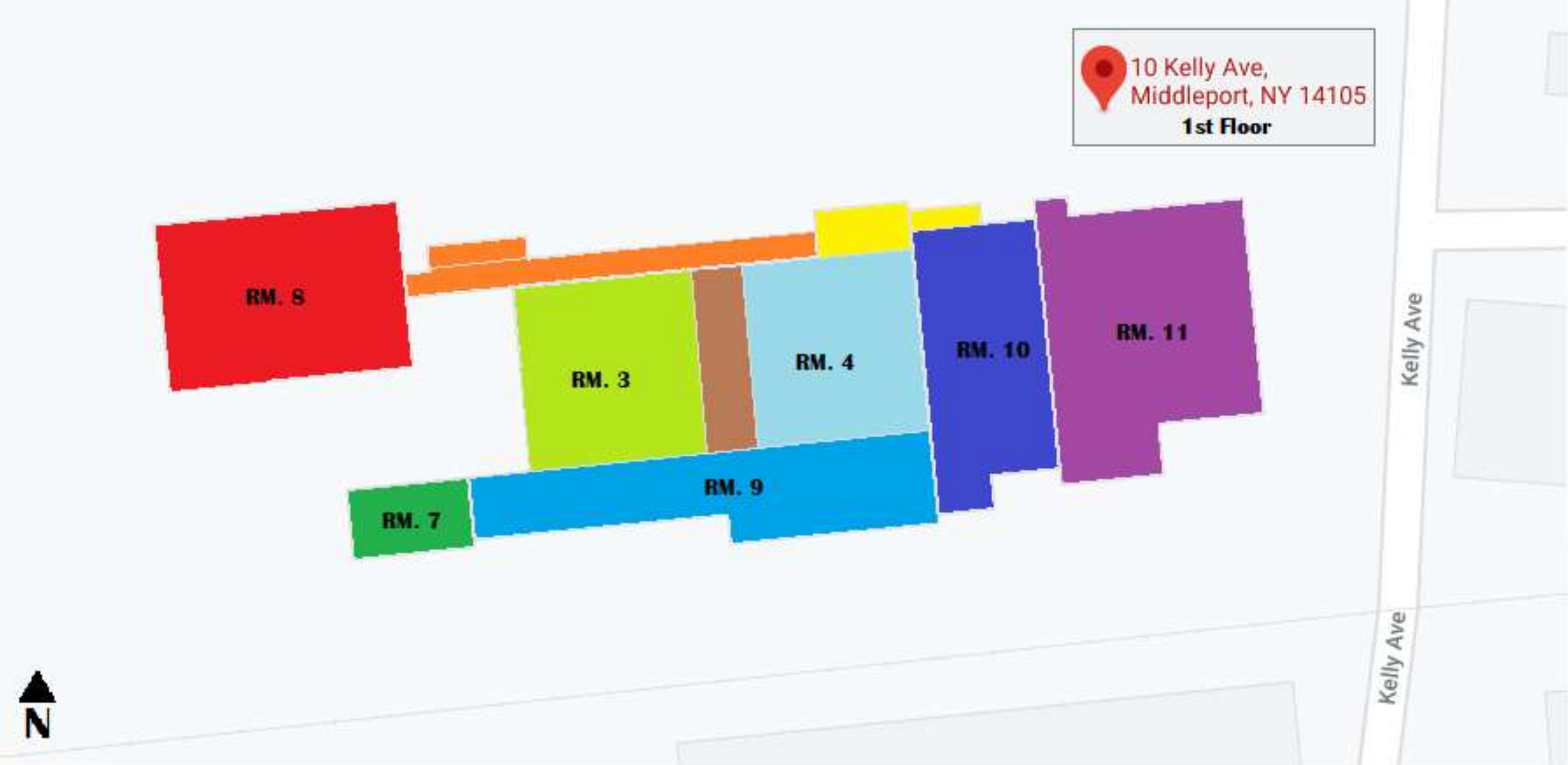
- Project Overview
- Facility Specs
- Production Requirements

- Worked Example
- Methods
- Limitations
- Final Design

Project Overview and Milestones

- Startup company looking to manufacture board games on a medium-scale
- Contract jobs to meet surge in demands – flexible manufacturing model
- Middleport, NY (Niagara County)
- Site visit on 3/29, meet with owner
- Progress meetings with Professor Becker on 4/3 and 4/21
- Buffalo Games tour 4/18

Facility Specifications



- 🟠 Loading dock platform with 2 dock levelers and grade level access
- 🟤 1,800 SF of common area for loading/unloading
- 🔵 6,500 SF, 13' clear ceiling, 1 loading door
- 🟢 6,500 SF, 13' clear ceiling, 1 loading door
- 🔴 10,000 SF, 21' clear ceiling, 2 loading doors
- 🟡 1,500 SF of office space (4 offices)
- 🟢 1,200 SF, 23' clear ceiling, 1 loading doors
- 🔵 6,500 SF, 13' clear ceiling, 1 loading door
- 🔵 7,000 SF, 12' clear ceiling, 2 loading doors
- 🟣 12,000 SF, 12-14' clear ceiling, 2 loading doors

Hellner Development Company LLC

Facility Specifications

- Standalone building
- Rectangular and empty
- 10,000 sqft. w/ 21 ft. ceiling
- Water: 8” main
- Electric: 480 3-phase
- Rail access

Hellner Development Co. is build-to-suit

Production Requirements

RAW MATERIAL

Cardboard
Paper
Plastic
Outsourced

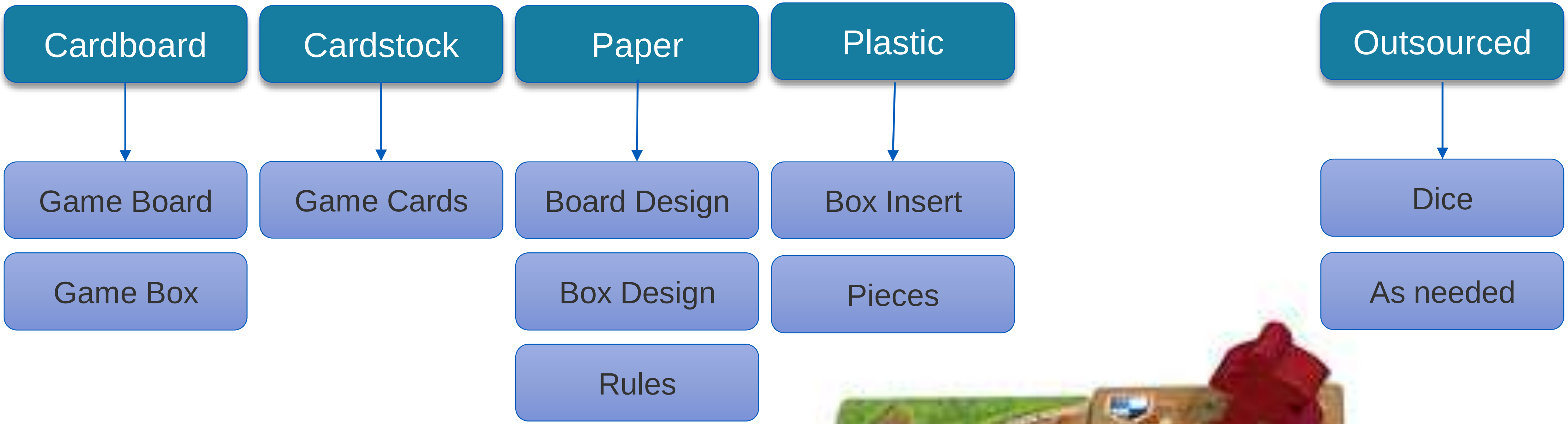
PROCESSING

Printing
Cutting
Gluing
Injection Molding
Assembly
Palletizing

FLEXIBILITY

Size of Gameboard
Game Components
Order Quantiy
Production Schedule

Raw Materials Chart



Cardboard → Game Board, Game Box

Cardstock → Game Cards

Paper → Board Design, Box Design, Rules

Plastic → Box Insert, Pieces

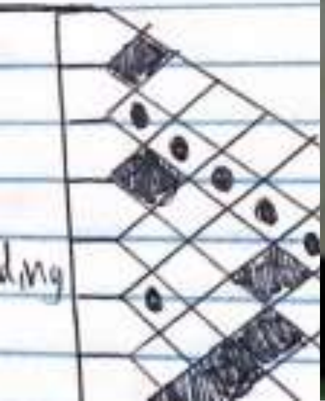
Outsourced → Dice, As needed

Mat'l → cardbo

Re ceive
↓
box Storage
↓ board

products

board	A	pr
box	B	
pieces	C	
cards	D	



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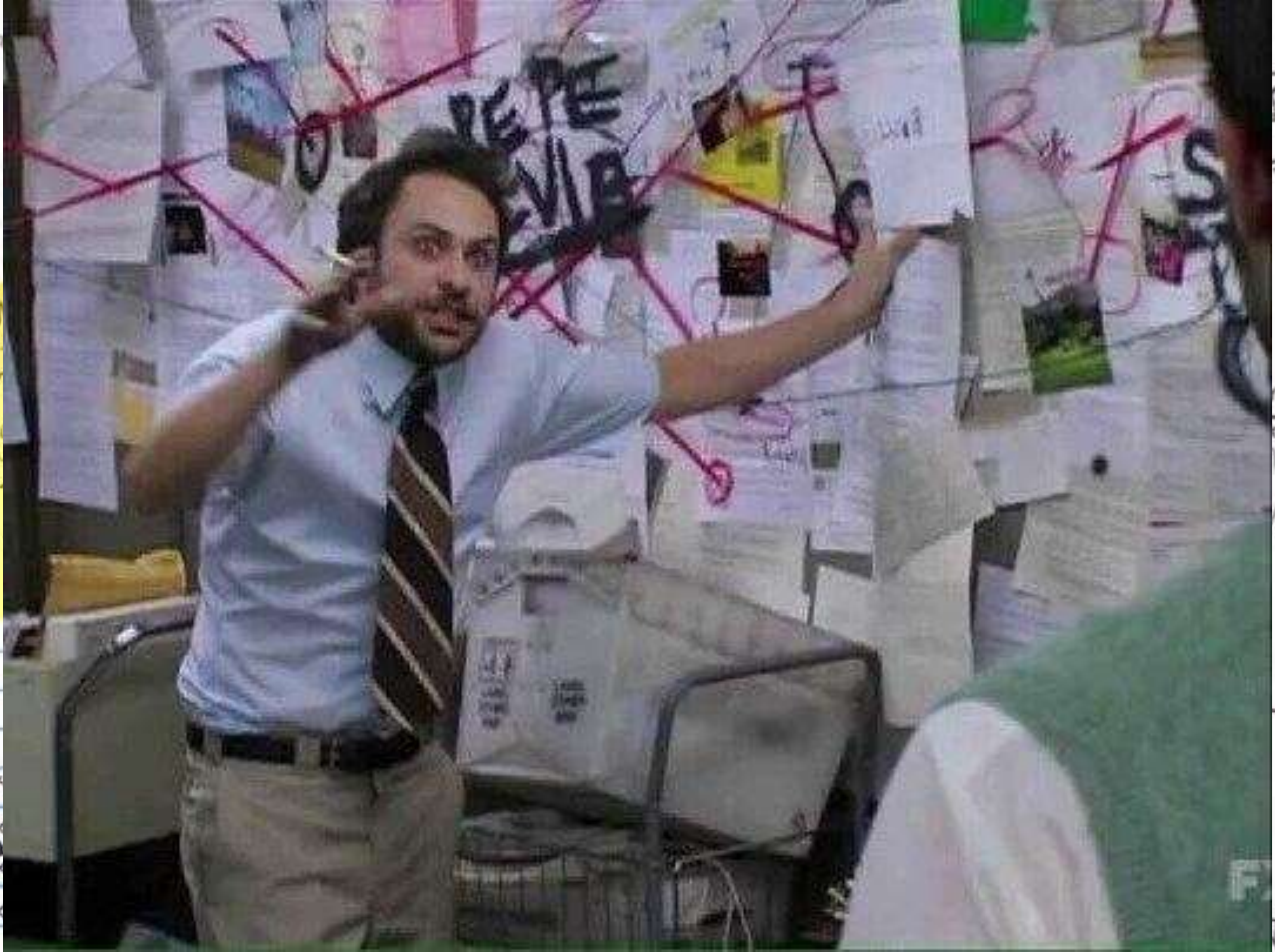

board

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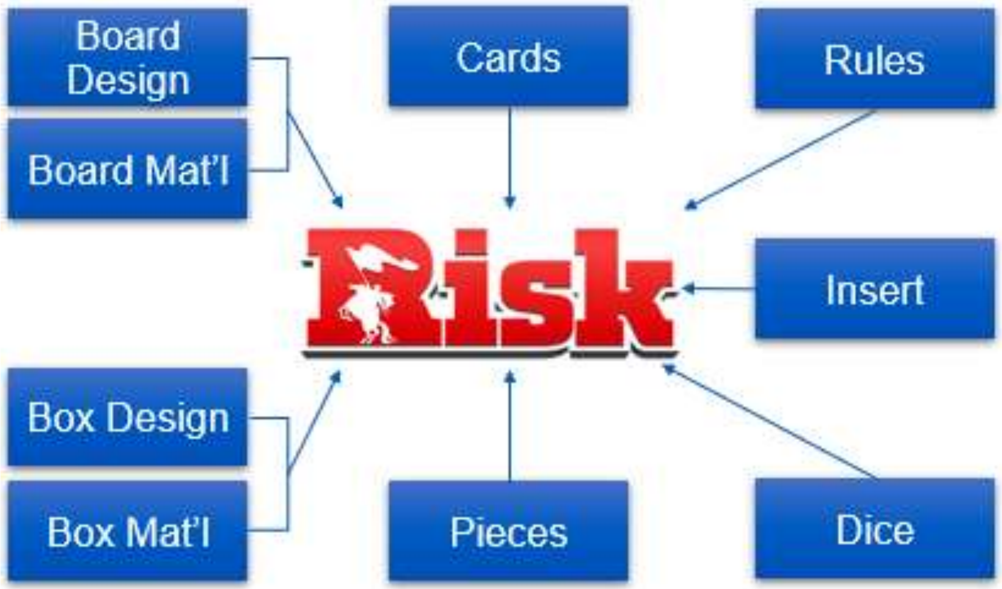
Process Flow Example

Risk

Methods: Bill of Materials and Assembly Chart

Level	Part #	Part Name	Make/Buy	Qty.
2	P01	Game board	M	1
2	P02	Printed gameboard design	M	1
2	P03	Game box	M	1
2	P04	Printed box design	M	1
1	P05	Plastic box Insert	M	1
1	P06	Infantry	M	200
1	P07	Cavalry	M	60
1	P08	Artillery	M	40
1	P09	Cards	M	56
1	P10	Dice	B	5
1	P11	Gameplay Rules	M	1
1	F01	Finished Gameboard	M	1
1	F02	Finished Box	M	1
0	G01	Finished Board Game	M	1



Methods: Department List and Route Chart

Department	Dept.
Shipping/Receiving	A
Storage Racks (S)	B
Printing	C
Gluing	D
Injection Moulding	E
3D Printing	F
Cutting	G
Assembly	H
Storage Racks (N)	I
Offices (2-story)	J
Maintenance	K

Part	Routing	Qty. per batch
Board	A-B1-G-D-H-A	1
Box	A-B1-G-D-H-A	1
Plastic Pieces	A-I-E-H-A	1.22
Cards	A-B2-C-G-H-A	6.22
Board Design	A-B2-C-G-D-H-A	1
Box Design	A-B2-C-G-D-H-A	1
Rules	A-B2-C-G-H-A	1
Dice	A-H-A	1

Assumed batch production of cards and injection molding

Methods: Flow-Between Chart

	A	B1	B2	C	D	E	G	H	I
A	-	2	9.22	0	0	0	0	14.4	1.22
B1		-	0	0	0	0	2	0	0
B2			-	9.22	0	0	0	0	0
C				-	0	0	9.22	0	0
D					-	0	4	4	0
E						-	0	1.22	1.22
G							-	7.22	0
H								-	0
I									-

- Establishes clear relationships
- Strong connection between A and H (Shipping/Receiving and Assembly)
- Plastic pieces are batched at high volume

Methods: DCA for Equipment

- Confirmed clustering of similar processes and part types
- Two separate sections of facility

Advantages
Simple to use
Clear solutions

Disadvantages
Works better with large number of products/machines

		Print	Cut	Glue	3D Print	Injection	
		1	5	2	3	4	
Board	A	1	1	1			3
Box	B	1	1				2
Cards	D	1	1				2
Pieces	C				1	1	2
		3	3	1	1	1	

Miscellaneous Departments

- Office Space: two-story modular pre-fab design
- 3D Printing area for prototyping
- Maintenance Crib

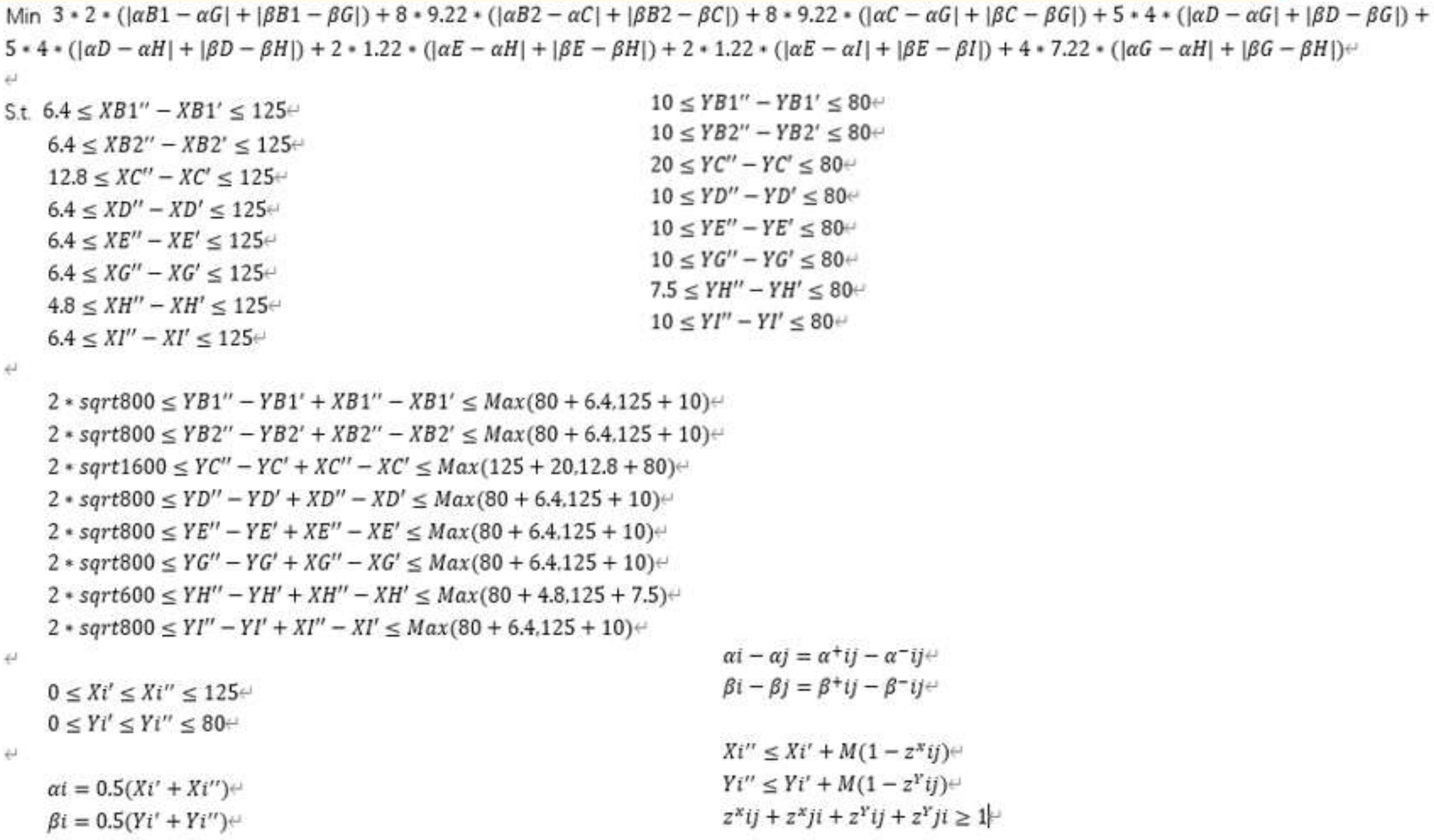
MIP Functions

Since

- department A: Shipping/ Receiving;
- department F: 3D Printing;
- department J: Office;
- department K: Maintenance

are Fixed.

Only consider B1, B2, C, D, E, G, H, I



Min $3*2*(|\alpha B1-\alpha G|+|\beta B1-\beta G|)+8*9.22*(|\alpha B2-\alpha C|+|\beta B2-\beta C|)+8*9.22*(|\alpha C-\alpha G|+|\beta C-\beta G|)+5*4*(|\alpha D-\alpha G|+|\beta D-\beta G|)+5*4*(|\alpha D-\alpha H|+|\beta D-\beta H|)+2*1.22*(|\alpha E-\alpha H|+|\beta E-\beta H|)+2*1.22*(|\alpha E-\alpha I|+|\beta E-\beta I|)+4*7.22*(|\alpha G-\alpha H|+|\beta G-\beta H|)$

S.t. $6.4 \le XB1'' - XB1' \le 125$

$6.4 \le XB2'' - XB2' \le 125$

$12.8 \le XC'' - XC' \le 125$

$6.4 \le XD'' - XD' \le 125$

$6.4 \le XE'' - XE' \le 125$

$6.4 \le XG'' - XG' \le 125$

$4.8 \le XH'' - XH' \le 125$

$6.4 \le XI'' - XI' \le 125$

$10 \le YB1'' - YB1' \le 80$

$10 \le YB2'' - YB2' \le 80$

$20 \le YC'' - YC' \le 80$

$10 \le YD'' - YD' \le 80$

$10 \le YE'' - YE' \le 80$

$10 \le YG'' - YG' \le 80$

$7.5 \le YH'' - YH' \le 80$

$10 \le YI'' - YI' \le 80$

$2*sqrt800 \le YB1'' - YB1' + XB1'' - XB1' \le Max(80+6.4,125+10)$

$2*sqrt800 \le YB2'' - YB2' + XB2'' - XB2' \le Max(80+6.4,125+10)$

$2*sqrt1600 \le YC'' - YC' + XC'' - XC' \le Max(125+20,12.8+80)$

$2*sqrt800 \le YD'' - YD' + XD'' - XD' \le Max(80+6.4,125+10)$

$2*sqrt800 \le YE'' - YE' + XE'' - XE' \le Max(80+6.4,125+10)$

$2*sqrt800 \le YG'' - YG' + XG'' - XG' \le Max(80+6.4,125+10)$

$2*sqrt600 \le YH'' - YH' + XH'' - XH' \le Max(80+4.8,125+7.5)$

$2*sqrt800 \le YI'' - YI' + XI'' - XI' \le Max(80+6.4,125+10)$

$0 \le Xi' \le Xi'' \le 125$

$0 \le Yi' \le Yi'' \le 80$

$\alpha i = 0.5(Xi' + Xi'')$

$\beta i = 0.5(Yi' + Yi'')$

$\alpha i - \alpha j = \alpha^{+}ij - \alpha^{-}ij$

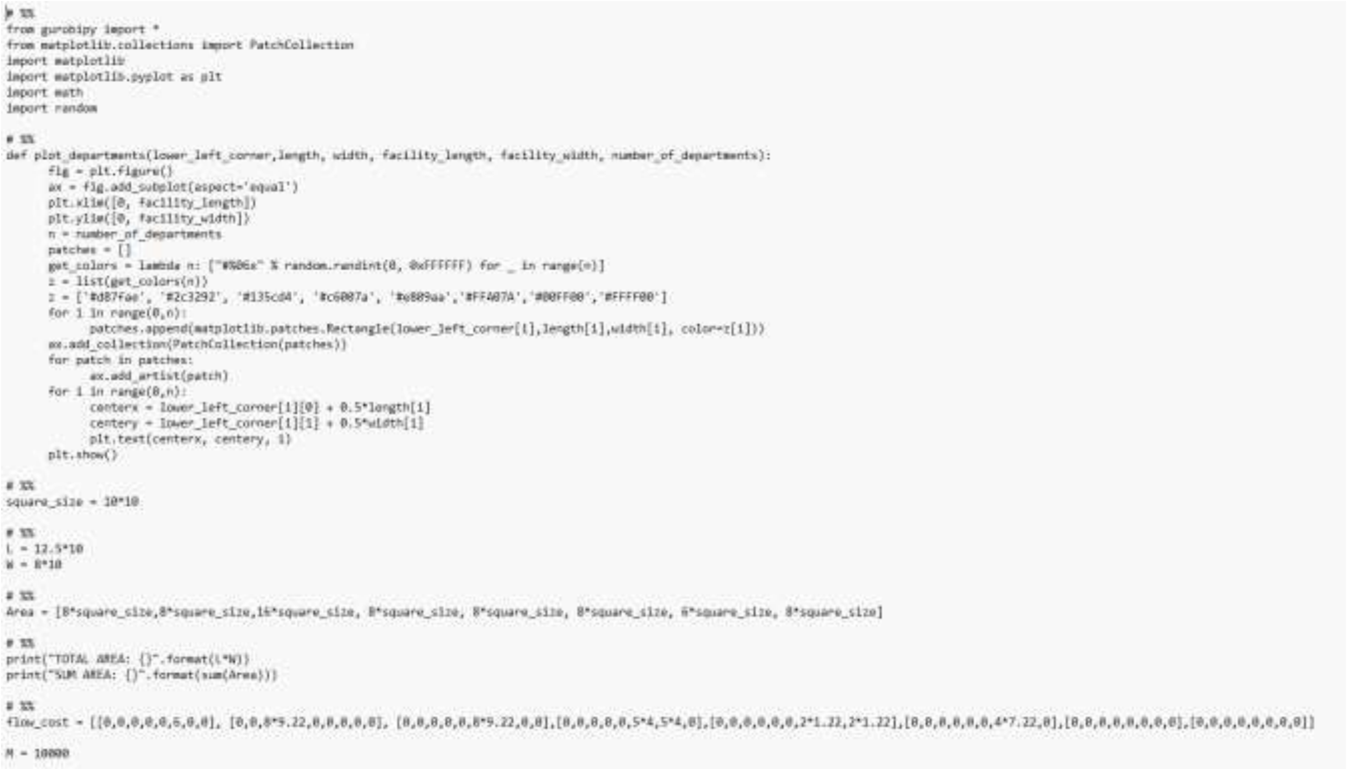
$\beta i - \beta j = \beta^{+}ij - \beta^{-}ij$

$Xi'' \le Xi' + M(1 - z^{x}ij)$

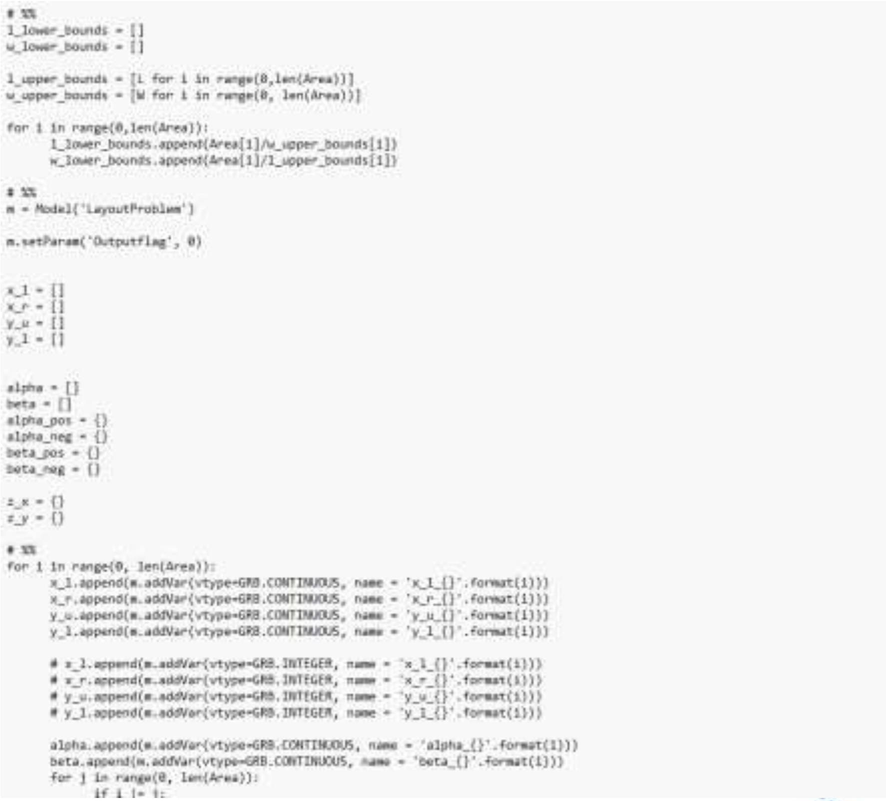
$Yi'' \le Yi' + M(1 - z^{Y}ij)$

$z^{x}ij + z^{x}ji + z^{Y}ij + z^{Y}ji \ge 1$

MIP Code (Partial)



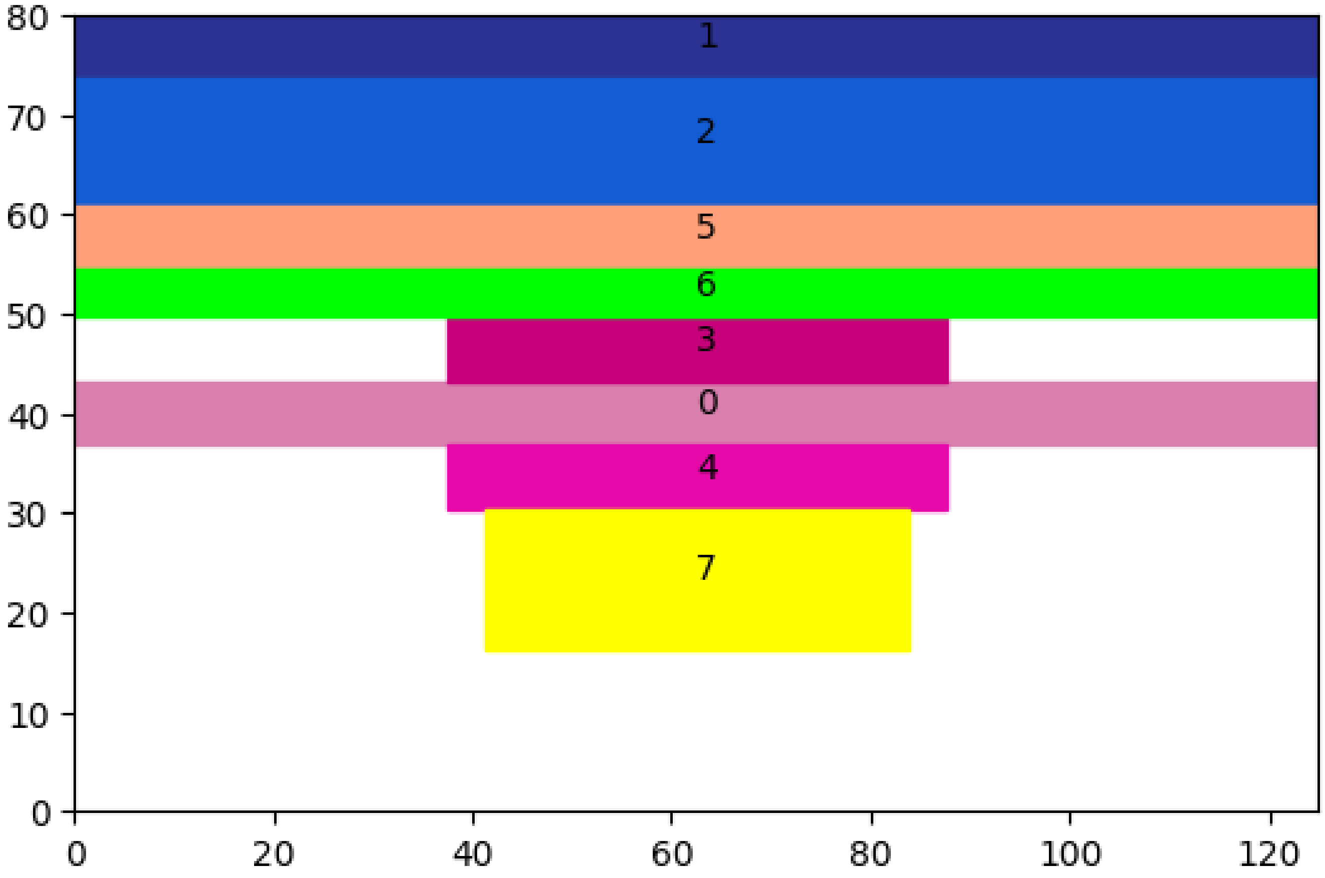
```
# %%
from gurobipy import *
from matplotlib.collections import PatchCollection
import matplotlib
import matplotlib.pyplot as plt
import math
import random

# %%
def plot_departments(lower_left_corner,length, width, facility_length, facility_width, number_of_departments):
      fig = plt.figure()
      ax = fig.add_subplot(aspect='equal')
      plt.xlim([0, facility_length])
      plt.ylim([0, facility_width])
      n = number_of_departments
      patches = []
      get_colors = lambda n: ["#%06x" % random.randint(0, 0xFFFFFF) for _ in range(n)]
      z = list(get_colors(n))
      z = ['#d87fae', '#2c3292', '#135cd4', '#c6007a', '#e809aa','#FFA07A','#00FF00','#FFFF00']
      for i in range(0,n):
            patches.append(matplotlib.patches.Rectangle(lower_left_corner[i],length[i],width[i], color=z[i]))
      ax.add_collection(PatchCollection(patches))
      for patch in patches:
            ax.add_artist(patch)
      for i in range(0,n):
            centerx = lower_left_corner[i][0] + 0.5*length[i]
            centery = lower_left_corner[i][1] + 0.5*width[i]
            plt.text(centerx, centery, i)
      plt.show()

# %%
square_size = 10*10

# %%
L = 12.5*10
W = 8*10

# %%
Area = [8*square_size,8*square_size,16*square_size, 8*square_size, 8*square_size, 8*square_size, 6*square_size, 8*square_size]

# %%
print("TOTAL AREA: {}".format(L*W))
print("SUM AREA: {}".format(sum(Area)))

# %%
flow_cost = [[0,0,0,0,0,6,0,0], [0,0,8*9.22,0,0,0,0,0], [0,0,0,0,0,8*9.22,0,0],[0,0,0,0,0,5*4,5*4,0],[0,0,0,0,0,0,2*1.22,2*1.22],[0,0,0,0,0,0,4*7.22,0],[0,0,0,0,0,0,0,0],[0,0,0,0,0,0,0,0]]

M = 10000
```



```
# %%
l_lower_bounds = []
w_lower_bounds = []

l_upper_bounds = [L for i in range(0,len(Area))]
w_upper_bounds = [W for i in range(0, len(Area))]

for i in range(0,len(Area)):
      l_lower_bounds.append(Area[i]/w_upper_bounds[i])
      w_lower_bounds.append(Area[i]/l_upper_bounds[i])

# %%
m = Model('LayoutProblem')

m.setParam('Outputflag', 0)


x_l = []
x_r = []
y_u = []
y_l = []


alpha = []
beta = []
alpha_pos = {}
alpha_neg = {}
beta_pos = {}
beta_neg = {}

z_x = {}
z_y = {}

# %%
for i in range(0, len(Area)):
      x_l.append(m.addVar(vtype=GRB.CONTINUOUS, name = 'x_l_{}'.format(i)))
      x_r.append(m.addVar(vtype=GRB.CONTINUOUS, name = 'x_r_{}'.format(i)))
      y_u.append(m.addVar(vtype=GRB.CONTINUOUS, name = 'y_u_{}'.format(i)))
      y_l.append(m.addVar(vtype=GRB.CONTINUOUS, name = 'y_l_{}'.format(i)))

      # x_l.append(m.addVar(vtype=GRB.INTEGER, name = 'x_l_{}'.format(i)))
      # x_r.append(m.addVar(vtype=GRB.INTEGER, name = 'x_r_{}'.format(i)))
      # y_u.append(m.addVar(vtype=GRB.INTEGER, name = 'y_u_{}'.format(i)))
      # y_l.append(m.addVar(vtype=GRB.INTEGER, name = 'y_l_{}'.format(i)))

      alpha.append(m.addVar(vtype=GRB.CONTINUOUS, name = 'alpha_{}'.format(i)))
      beta.append(m.addVar(vtype=GRB.CONTINUOUS, name = 'beta_{}'.format(i)))
      for j in range(0, len(Area)):
            if i != j:
```

MIP Result

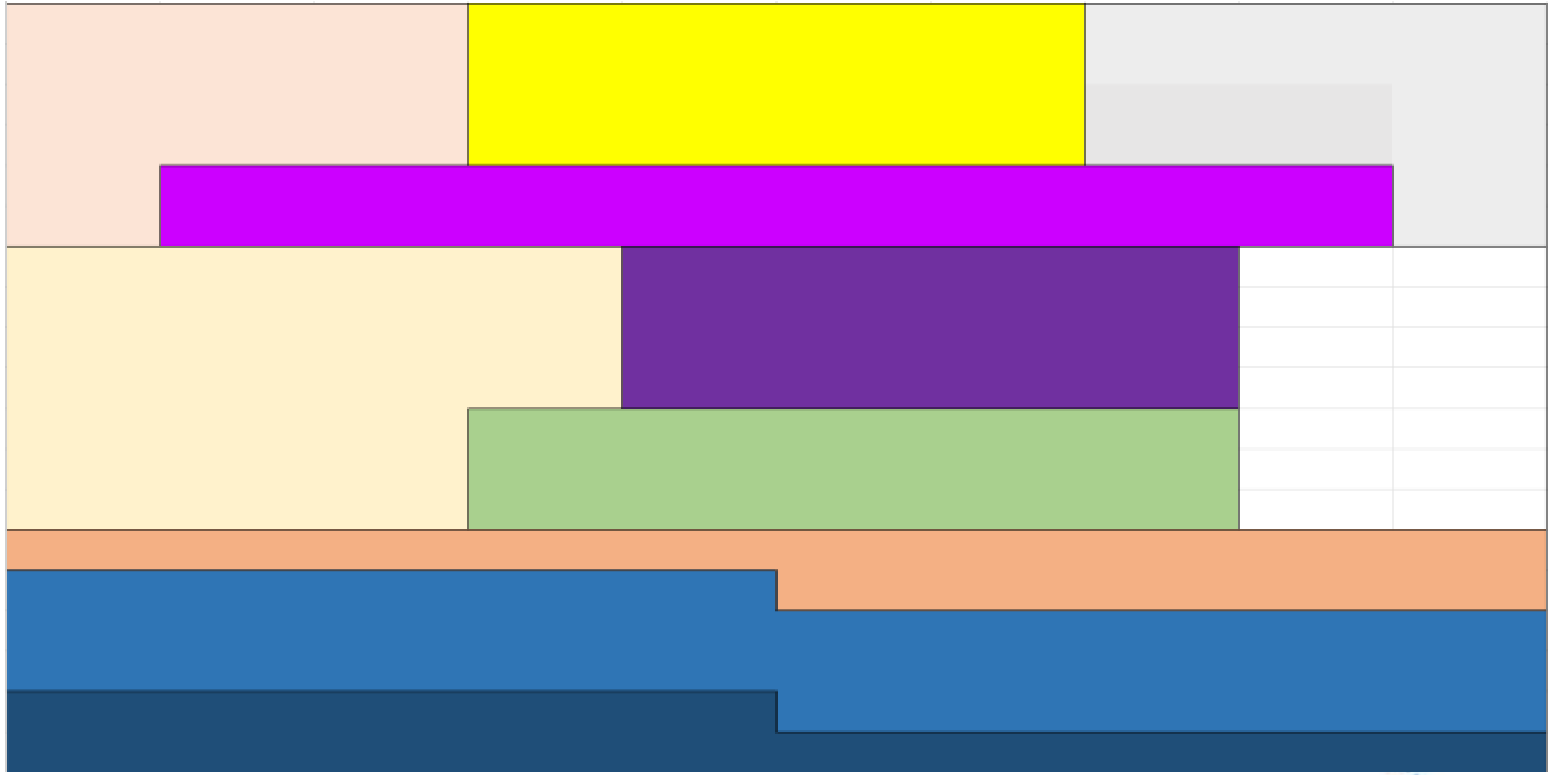
0 == Storage Rack 1
1 == Storage Rack 2
2 == Printing
3 == Gluing
4 == Injection Moulding
5 == Cutting
6 == Assembly
7 == Storage Rack 3



MIP Result Roughly Adjusted

Disadvantages:

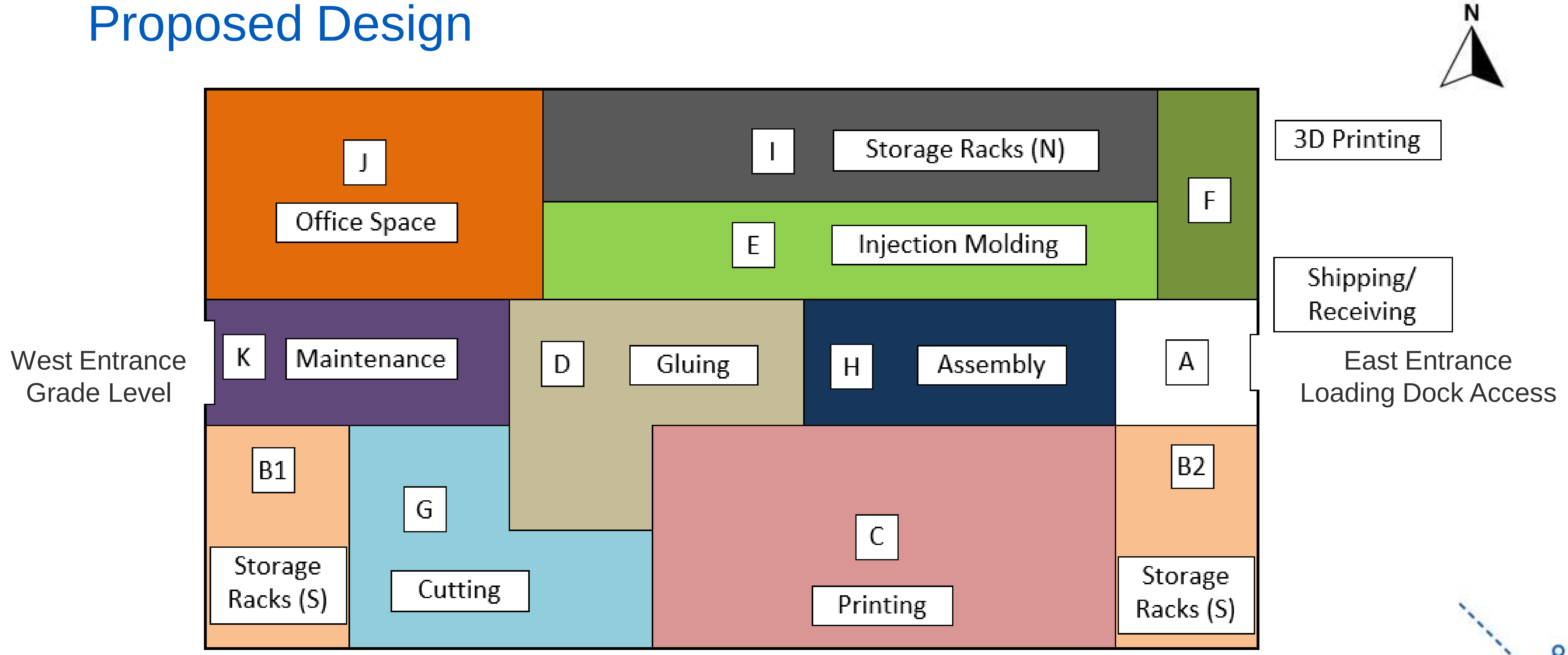
- Some of shapes are not good. The narrowest department is only 8 feet.
- Not easy to fit the size, shape, layout of machines.
- Difficult to decide the raw material warehouse and the product warehouse.
- Not match the result of DCA



Limitations

- Extremely specialized equipment
- Actual flow rates too high for size of building
- Irregular and static shape of machinery
  (e.g. printer is appx. 35 x 8 ft.)
- Scope of project much wider than 10-minute presentation

Proposed Design



Evaluating with CRAFT

Assumed C_{ij} is \$1 for all movement - could vary based on Material Handling methods

Fij	A	B1	B2	C	D	E	F	G	H	I	J	K
A	-	2	9.22	0	0	0	0	0	14.44	1.22	0	0
B1		-	0	0	0	0	0	2	0	0	0	0
B2			-	9.22	0	0	0	0	0	0	0	0
C				-	0	0	0	9.22	0	0	0	0
D												
E												
F												
G												
H												
I												
J												
K												

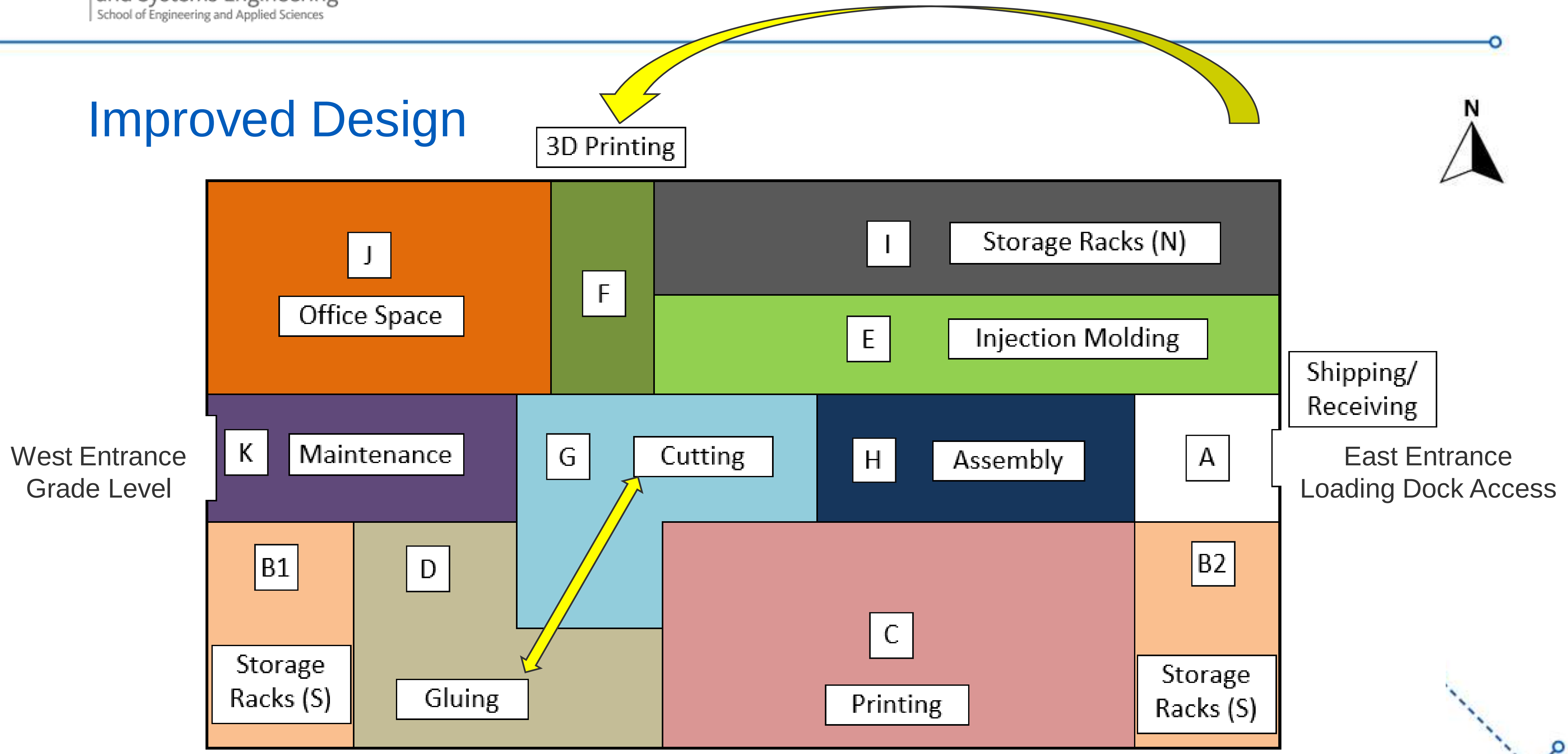
Dij	A	B1	B2	C	D	E	F	G	H	I	J	K
A	-	133	25	61.25	70.65	56.25	26.25	111.9	27.25	71.25	120.8	98.75
B1		-	108	71.75	62.35	108.8	159.3	25.95	105.8	123.8	60.25	34.25
B2			-	36.25	86.05	81.25	51.25	86.85	52.25	96.25	145.8	123.8
C				-	49.8	45	87.5	50.6	34	60	109.5	87.5
D					-	46.4	96.9	41.2	43.4	61.4	59.7	37.7
E						-	50.5	87.6	29	15	64.5	74.5
F							-	138.1	53.5	49.5	99	125
G								-	84.6	102.6	63.7	41.7
H									-	44	93.5	71.5
I										-	63.5	89.5
J											-	26
K												-

$$F_{ij} * C_{ij} * D_{ij} = 2832.5$$

Improvements: CRAFT

- Constrained dept. A (Shipping/Receiving) near east door
- Move dept. F (3D Printing) to the west of I and E
- Switch depts. D and G (Cutting and Gluing) for a 3% cost reduction

Improved Design



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