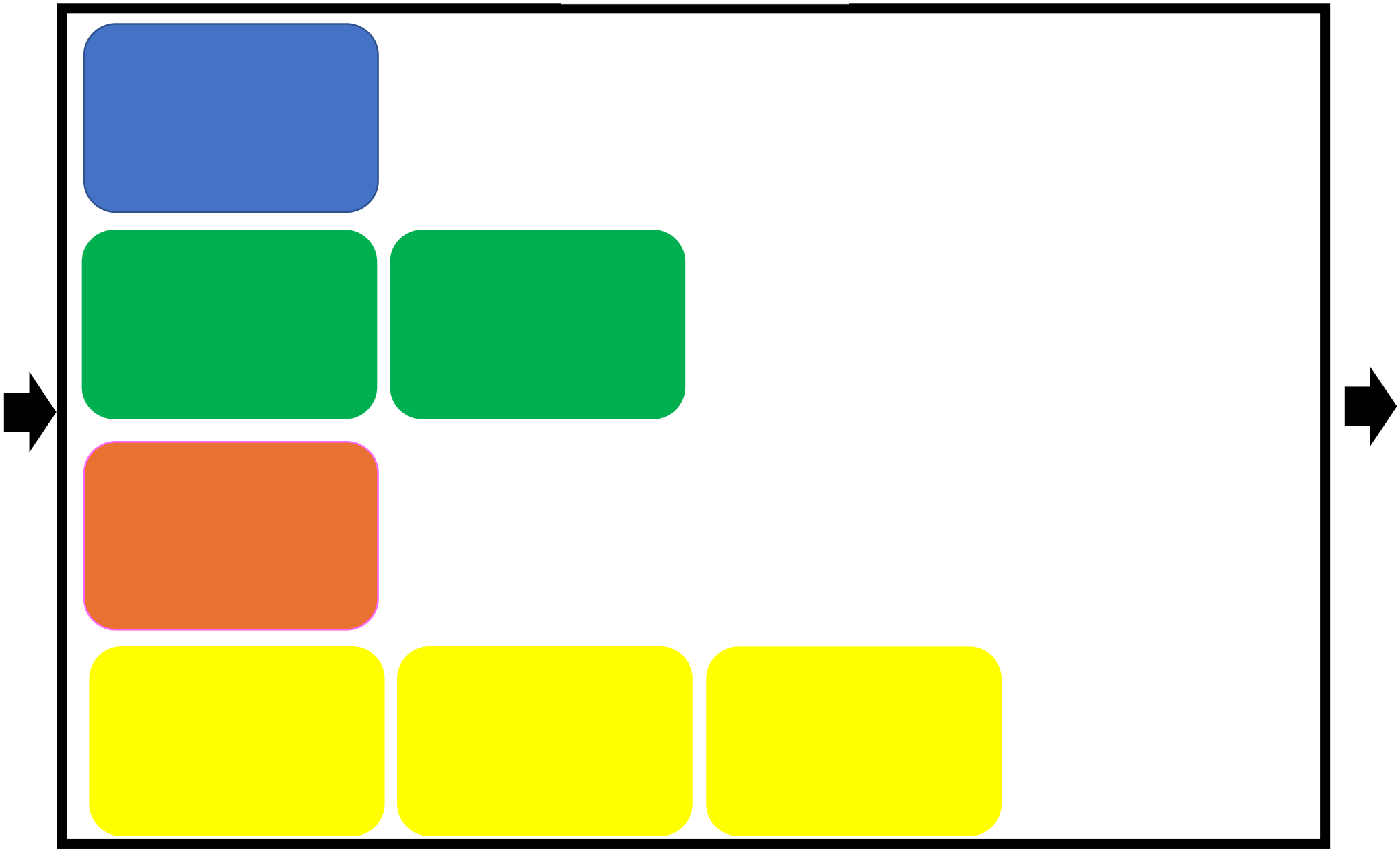
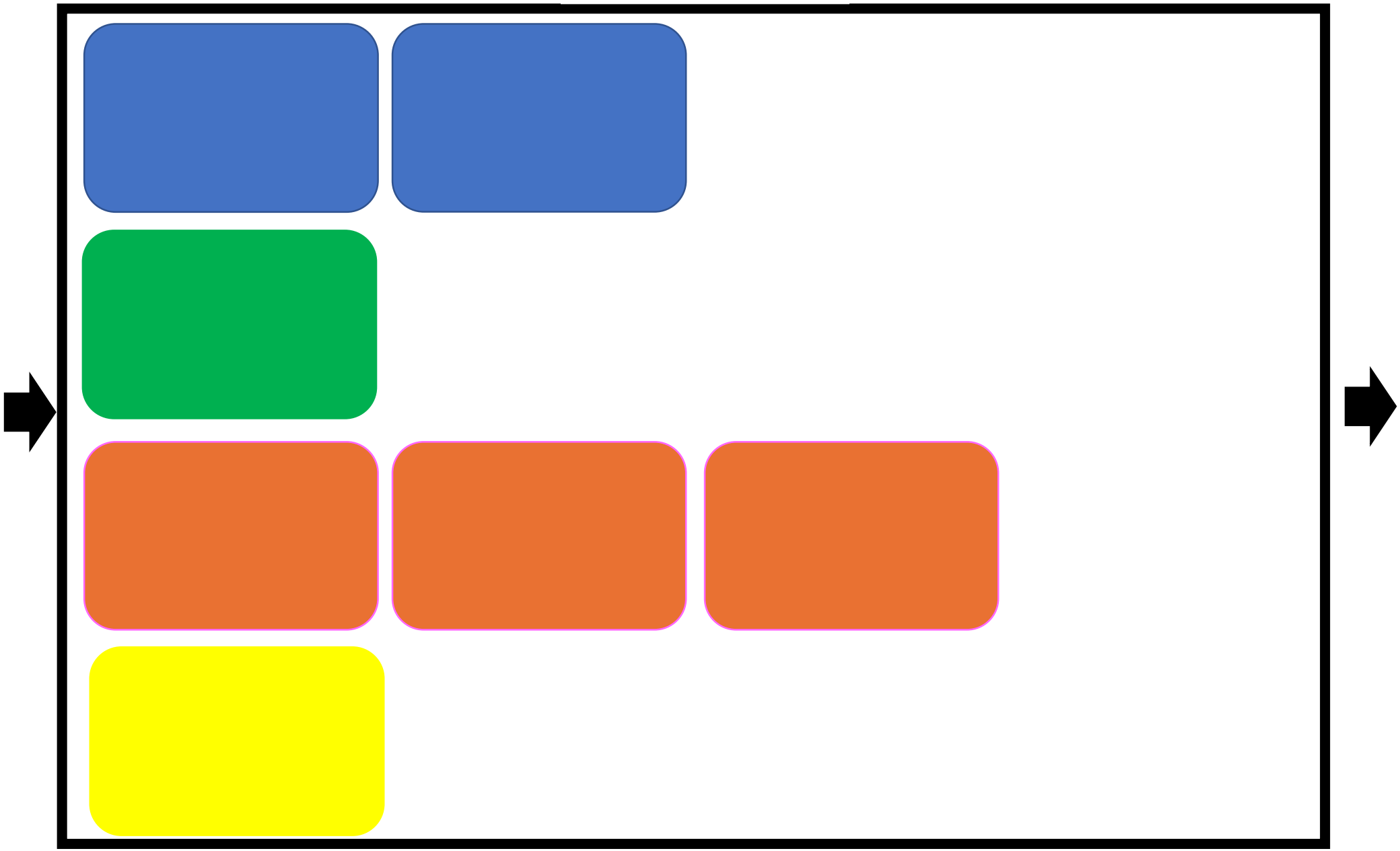
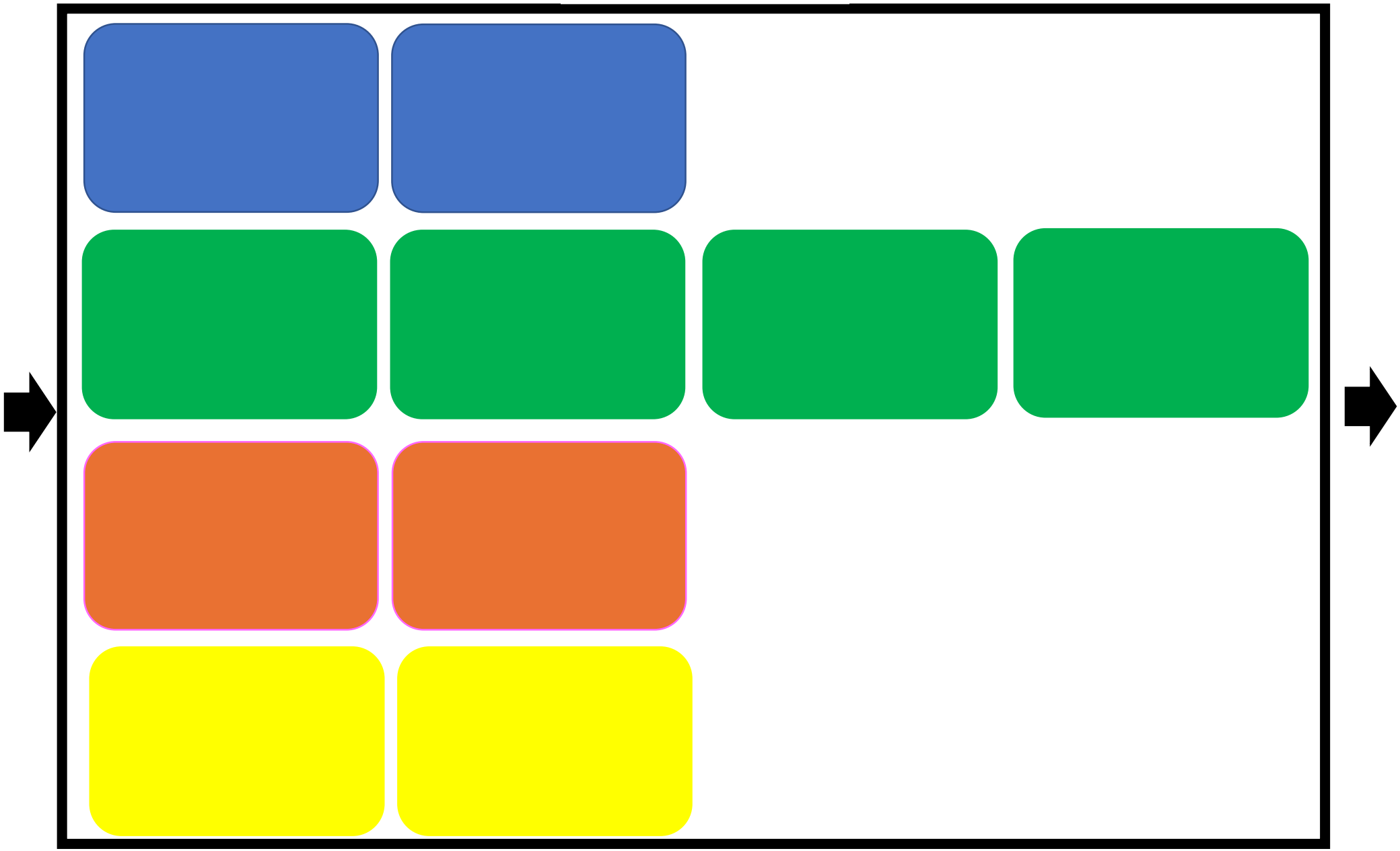
Machine 1



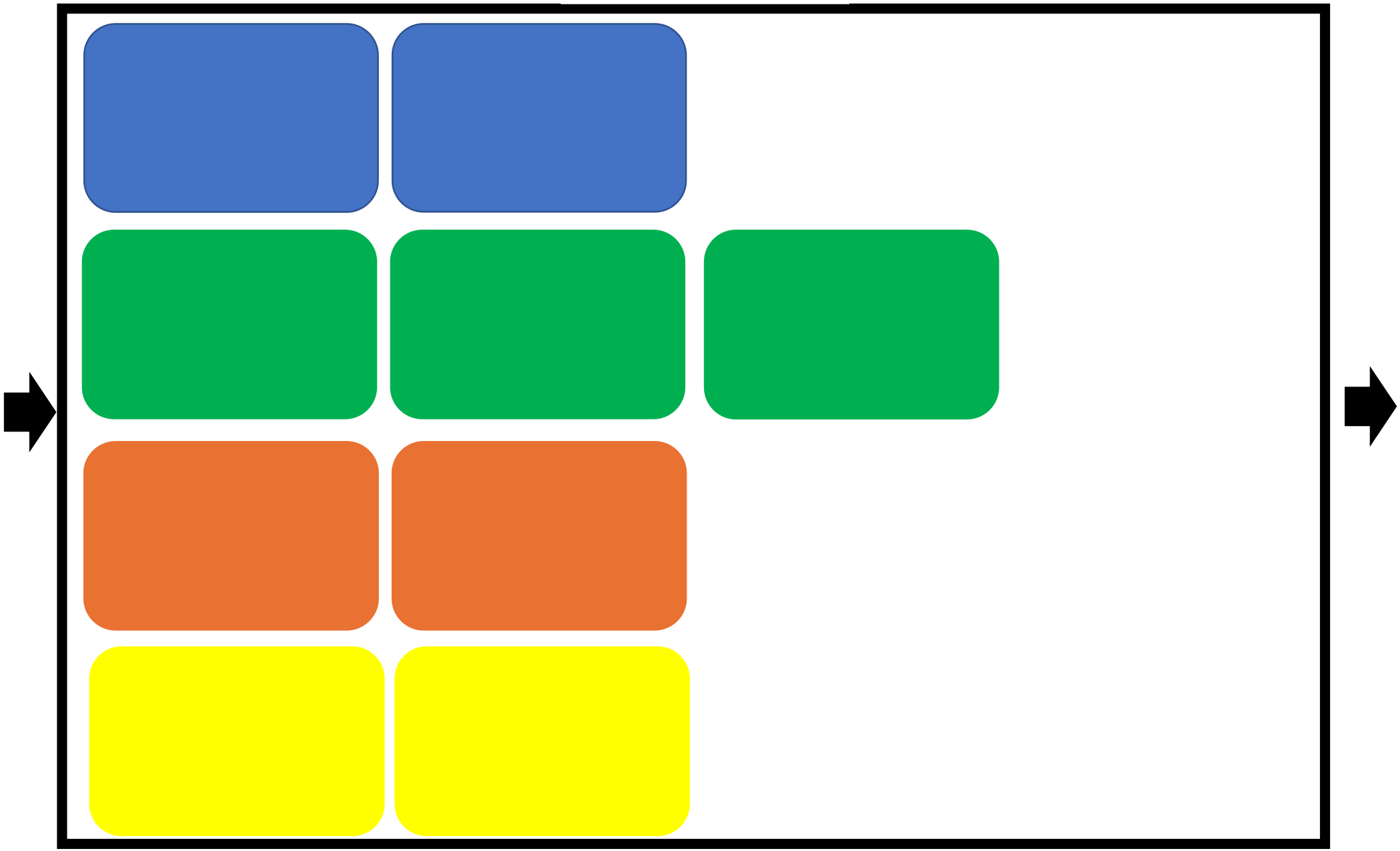
Machine 2



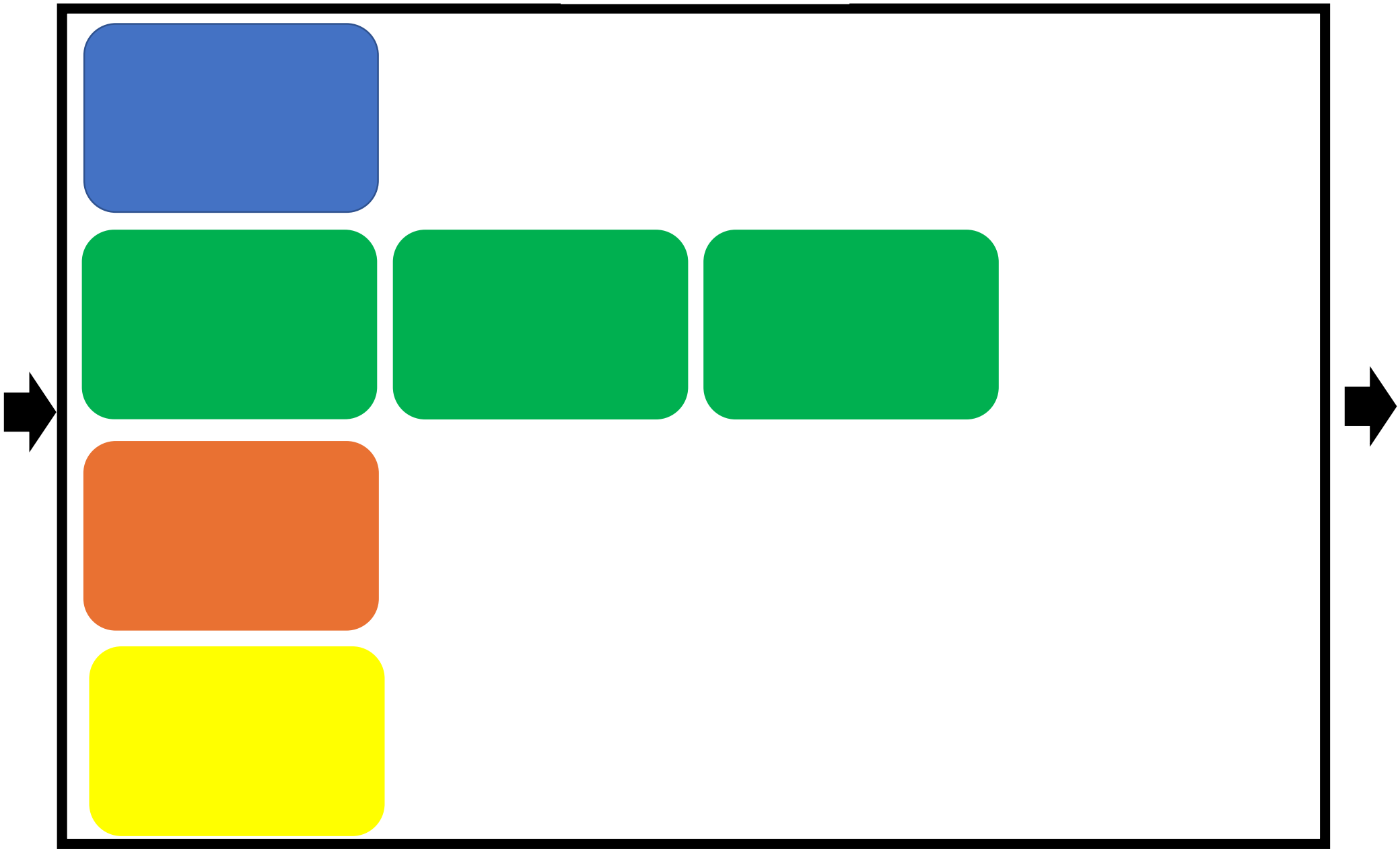
Machine 3

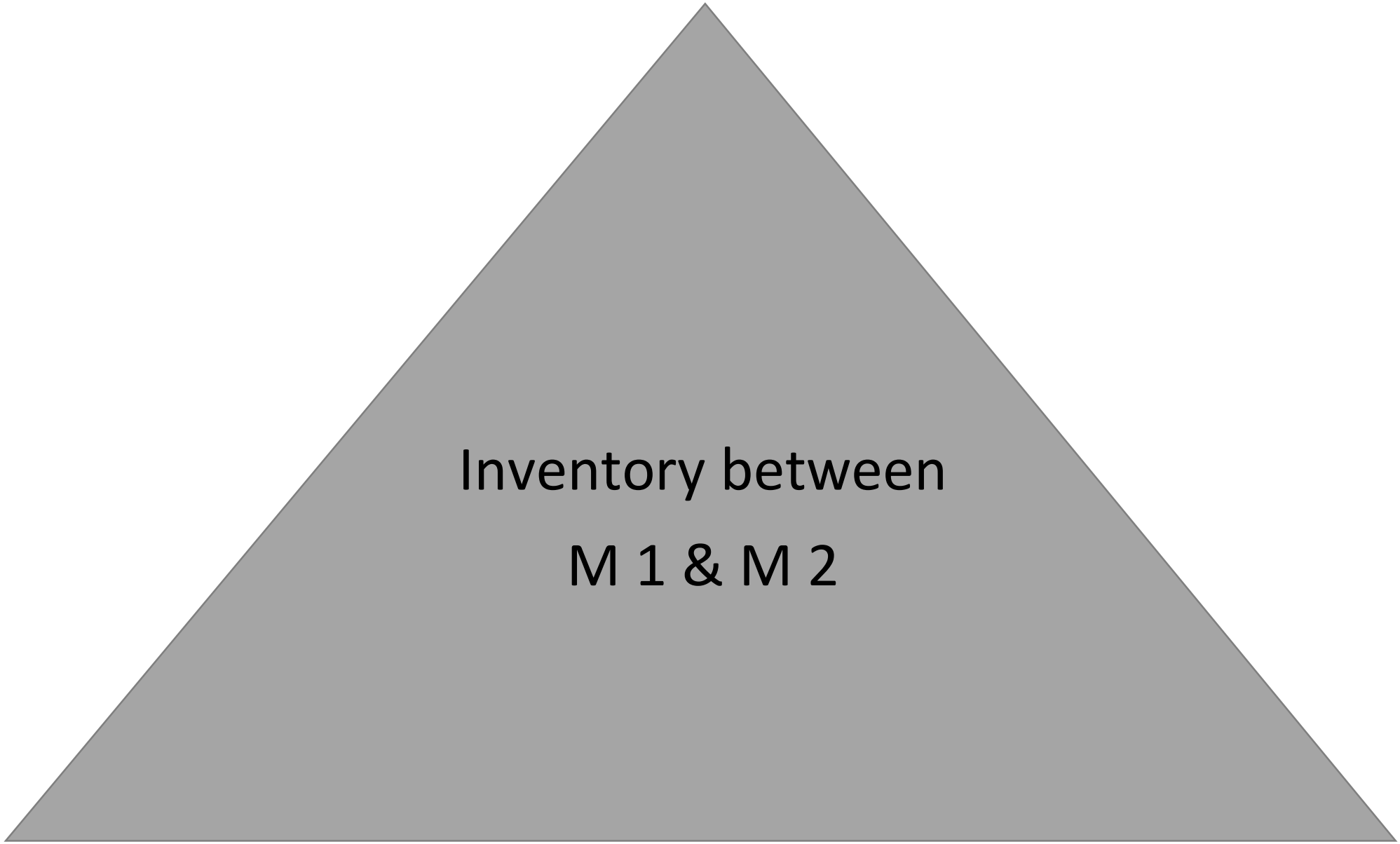


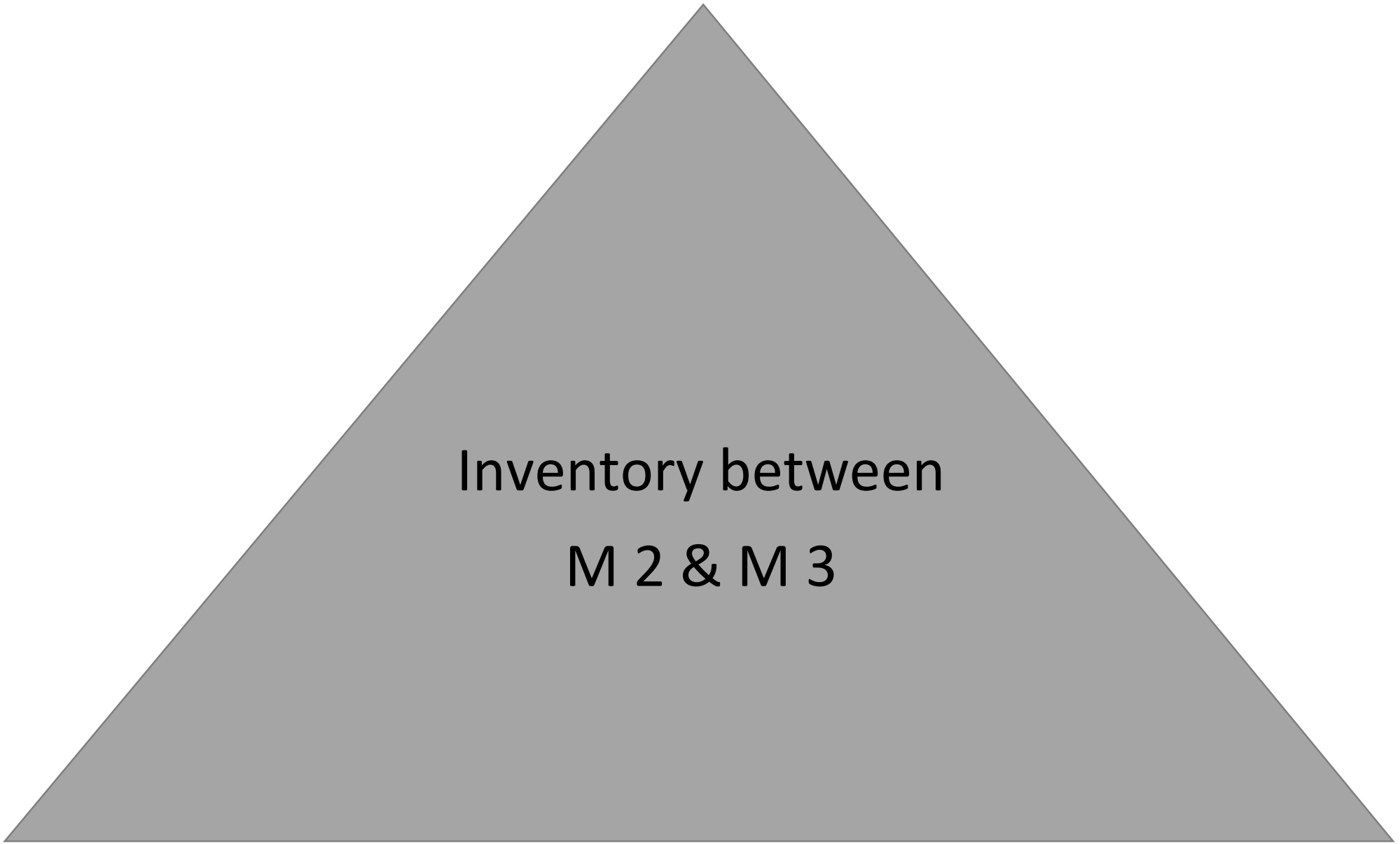
Machine 4

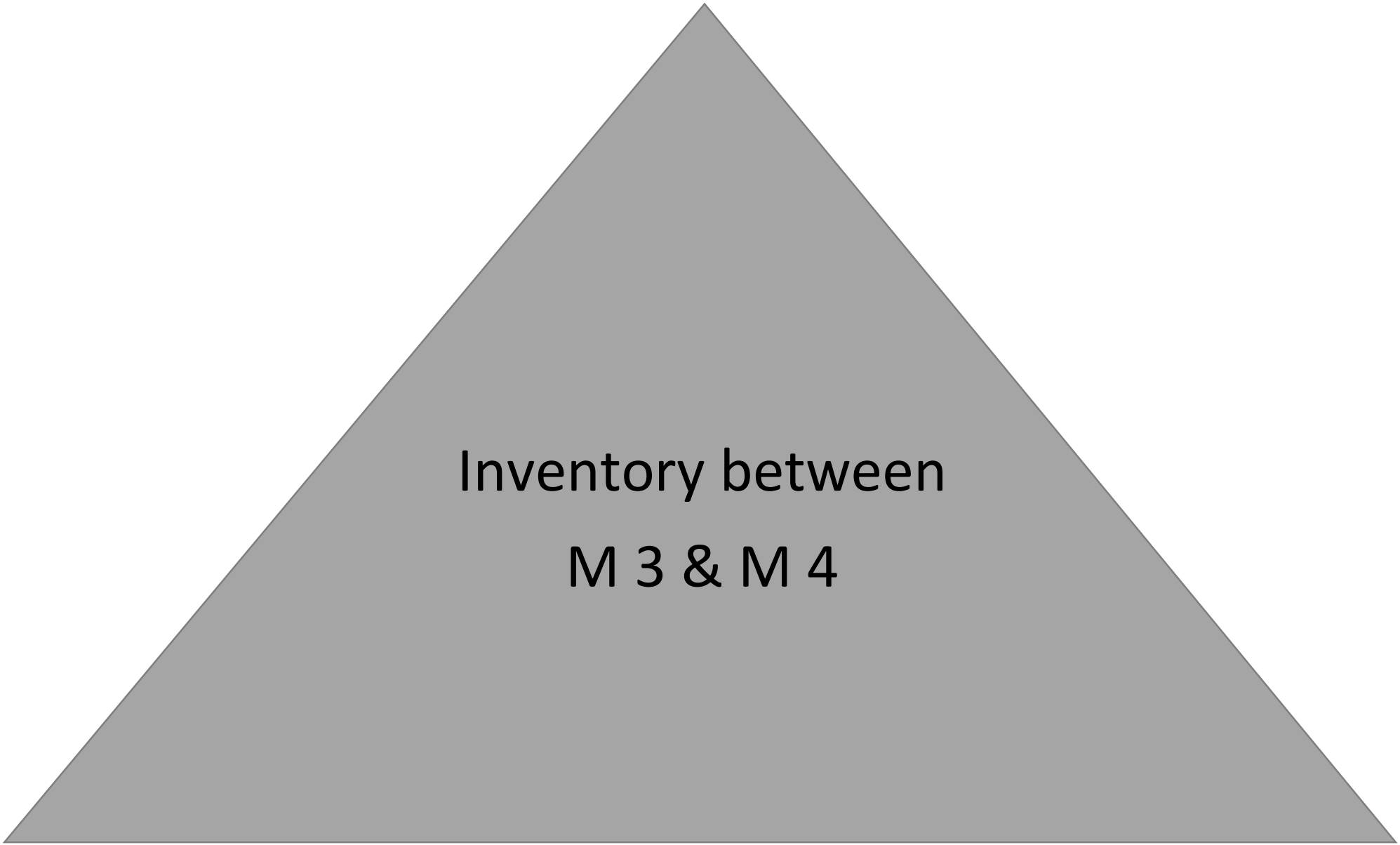


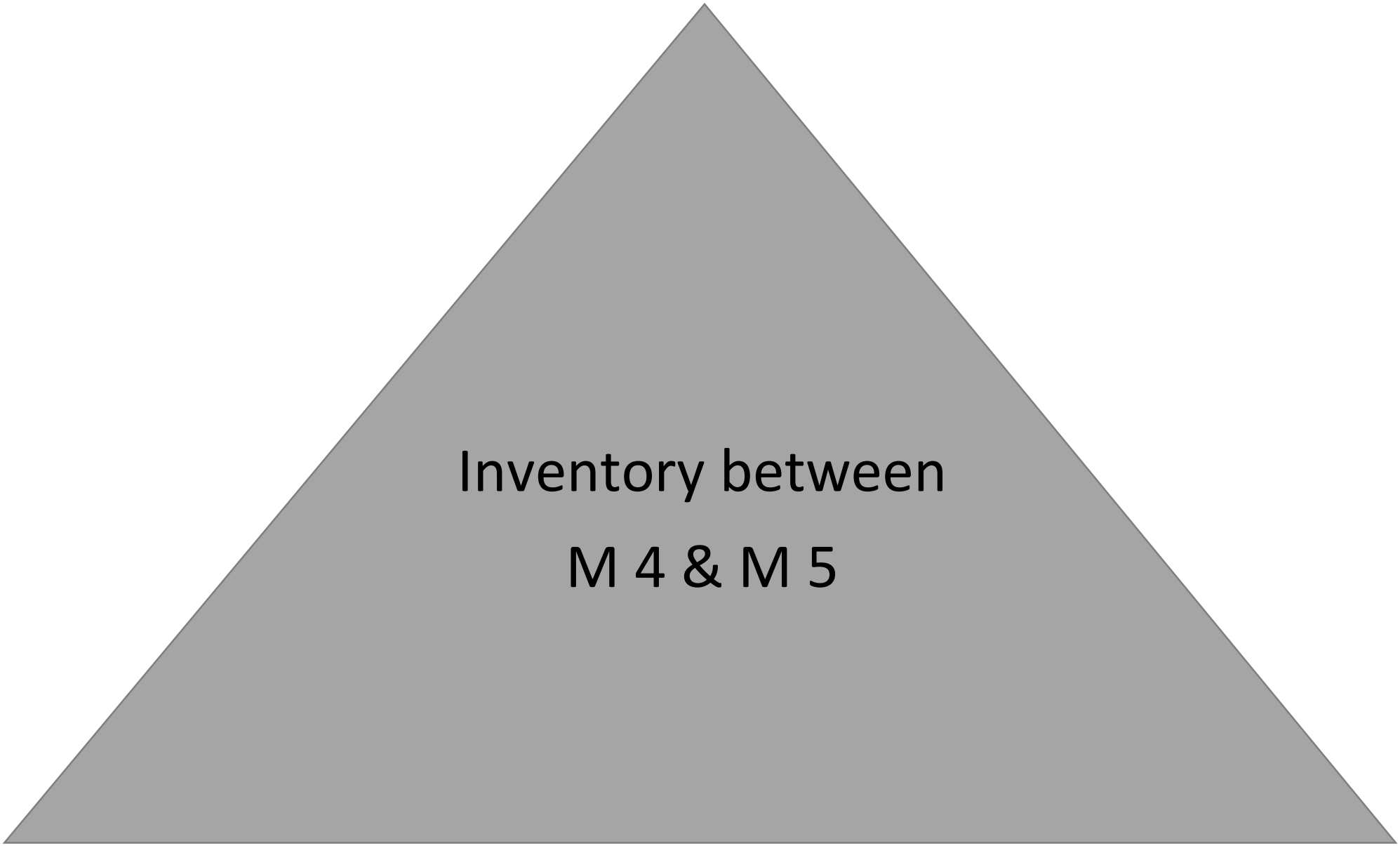
Machine 5

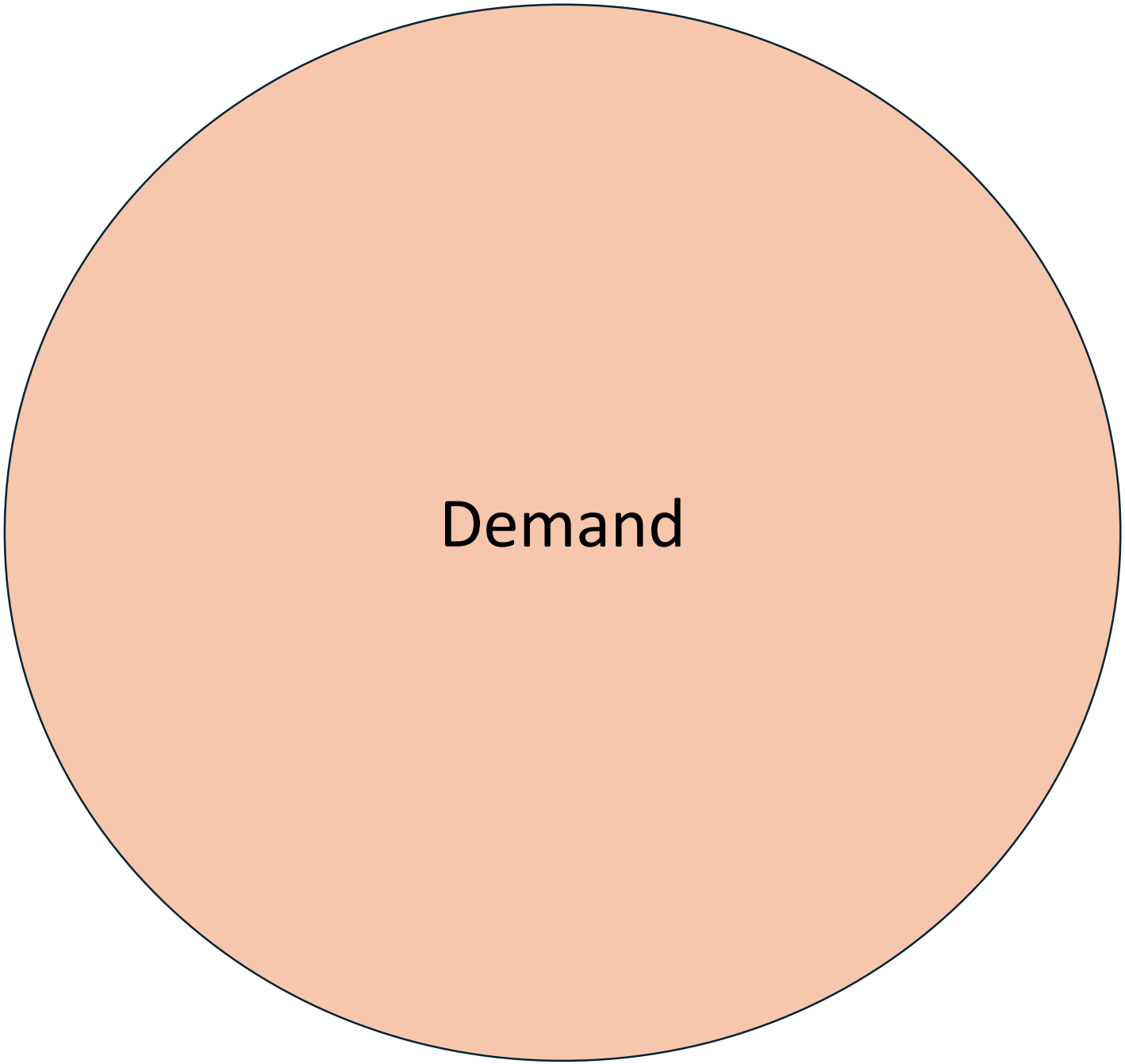



Inventory between
M 1 & M 2


Inventory between
M 2 & M 3

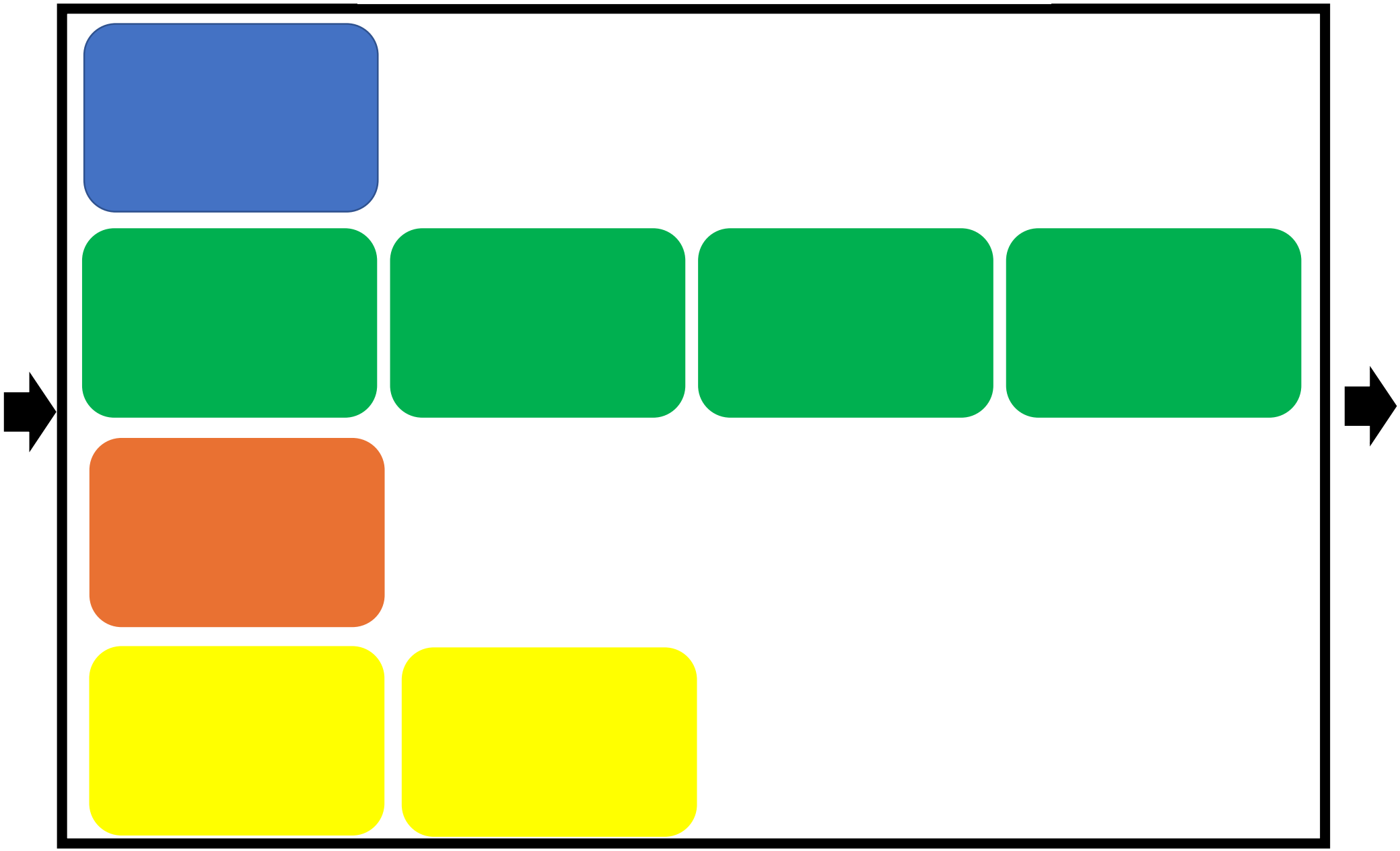

Inventory between
M 3 & M 4


Inventory between
M 4 & M 5

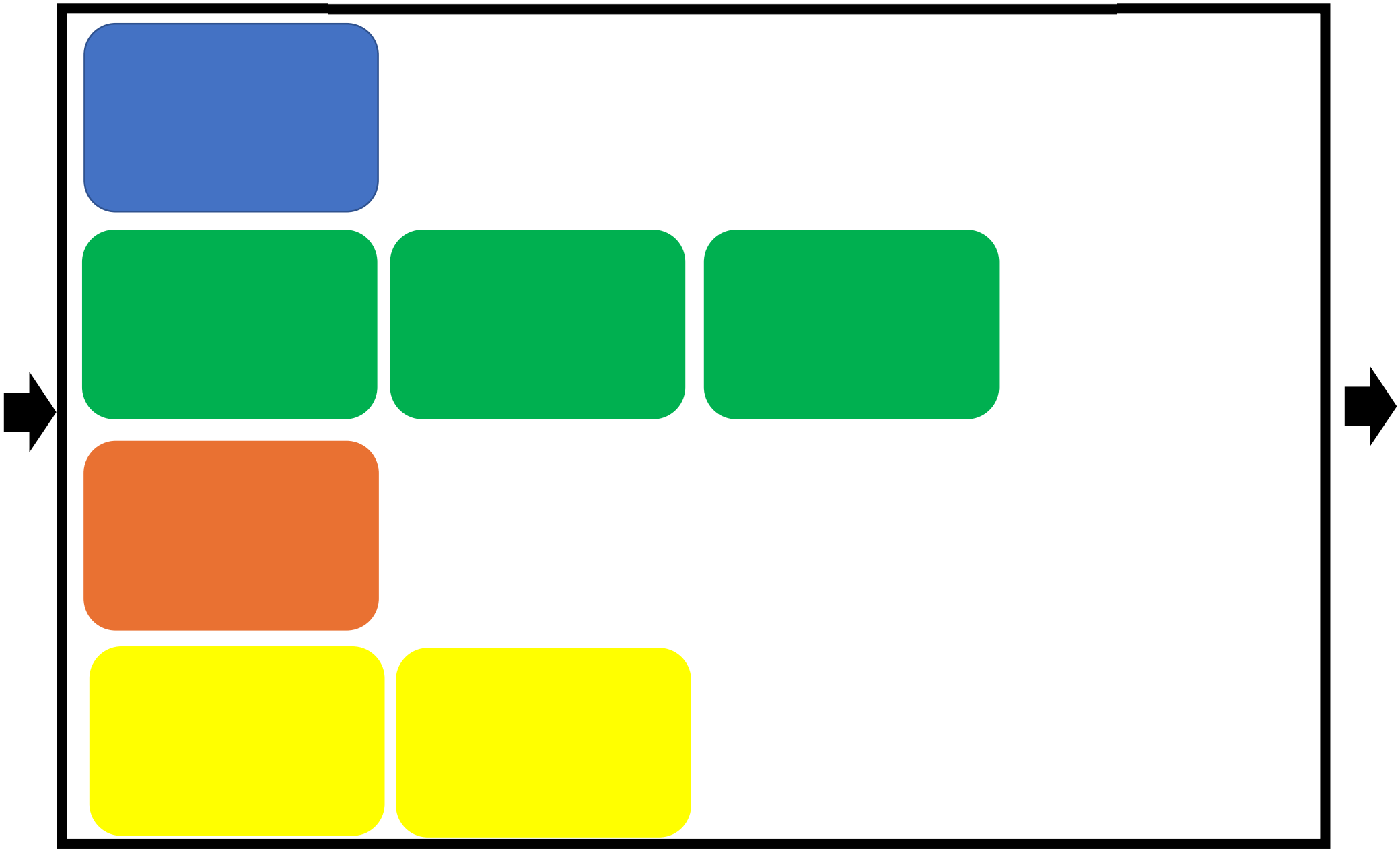

Demand


Finished goods

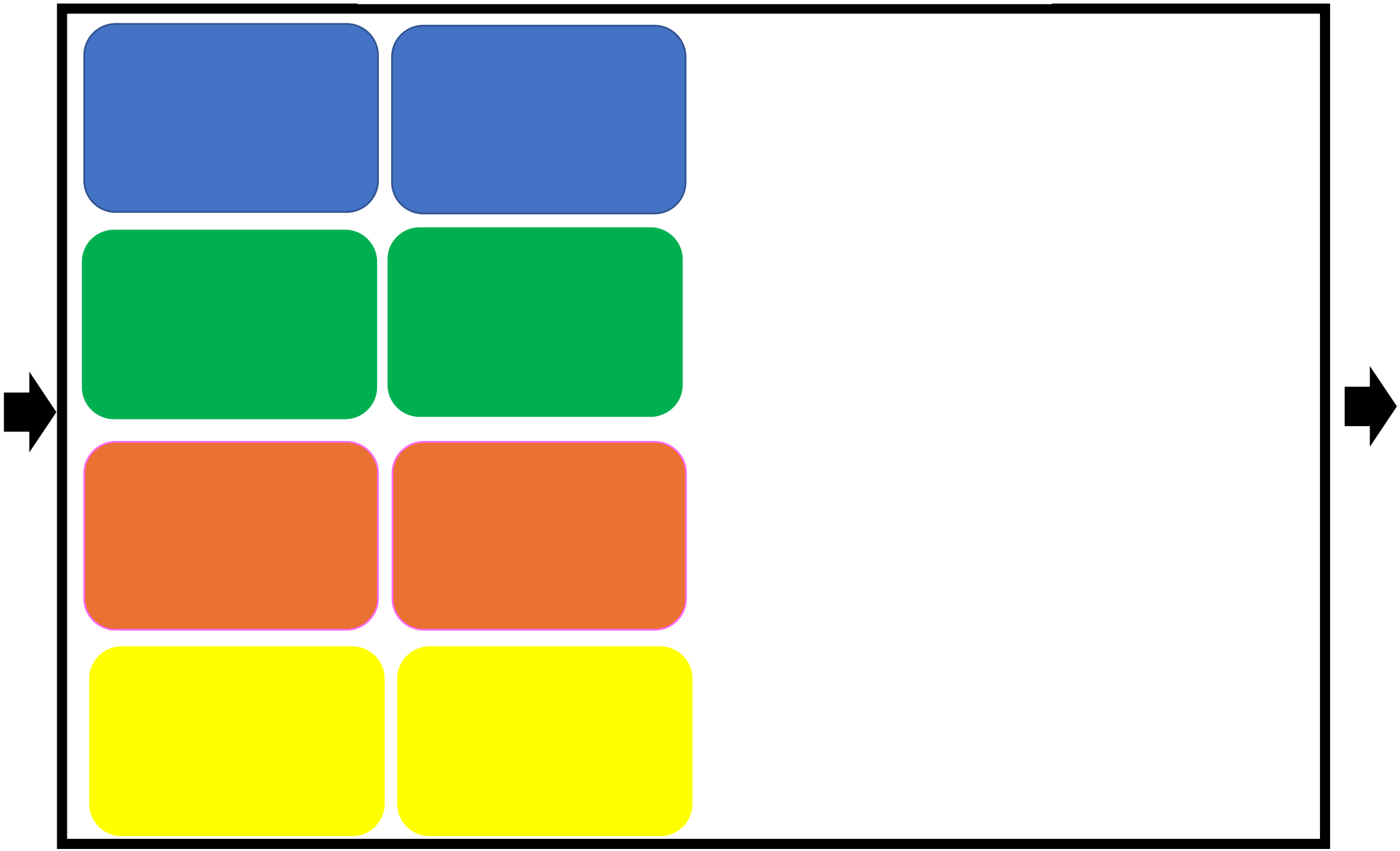
OPTION 1: New Machine 3



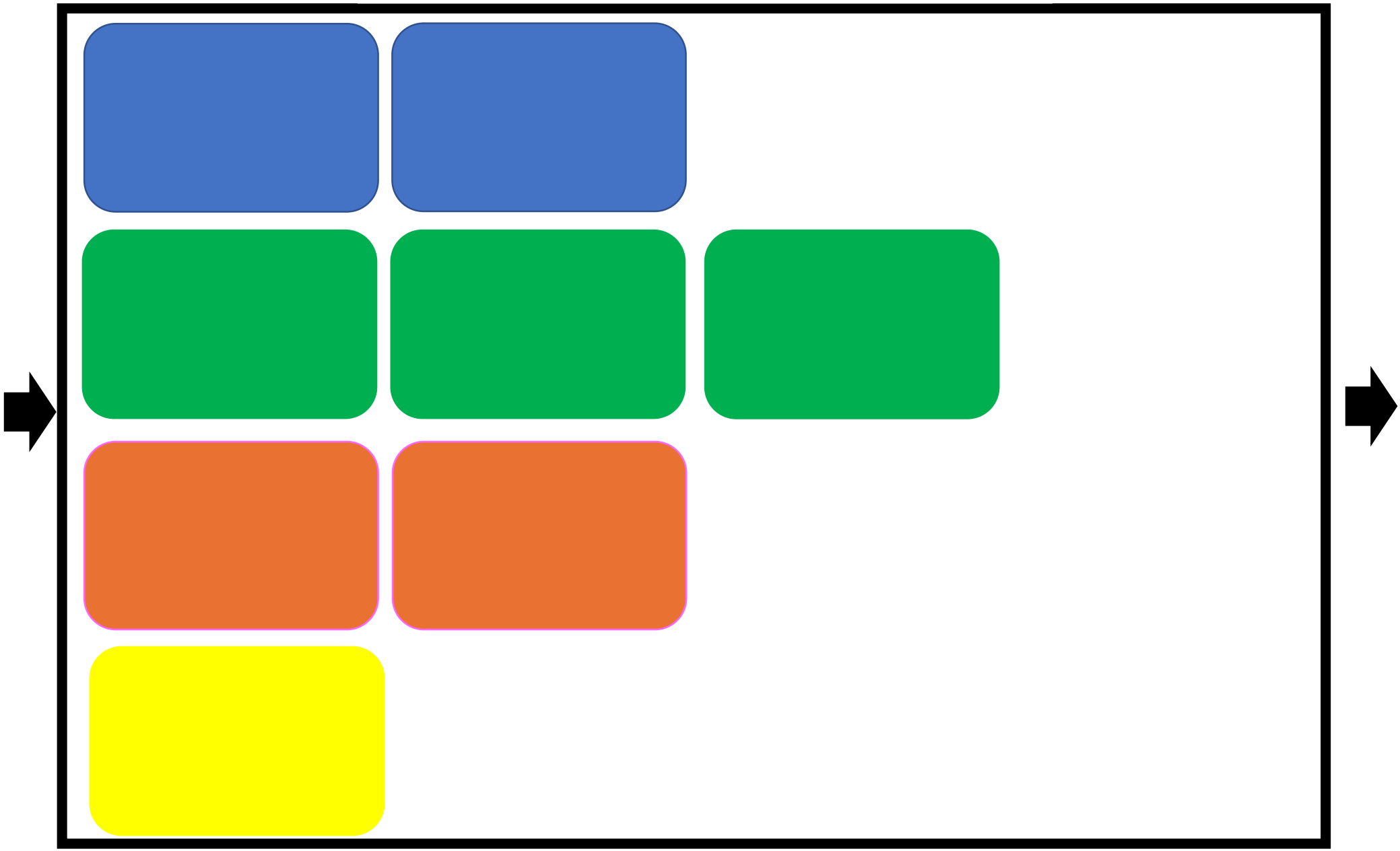
OPTION 1: New Machine 4



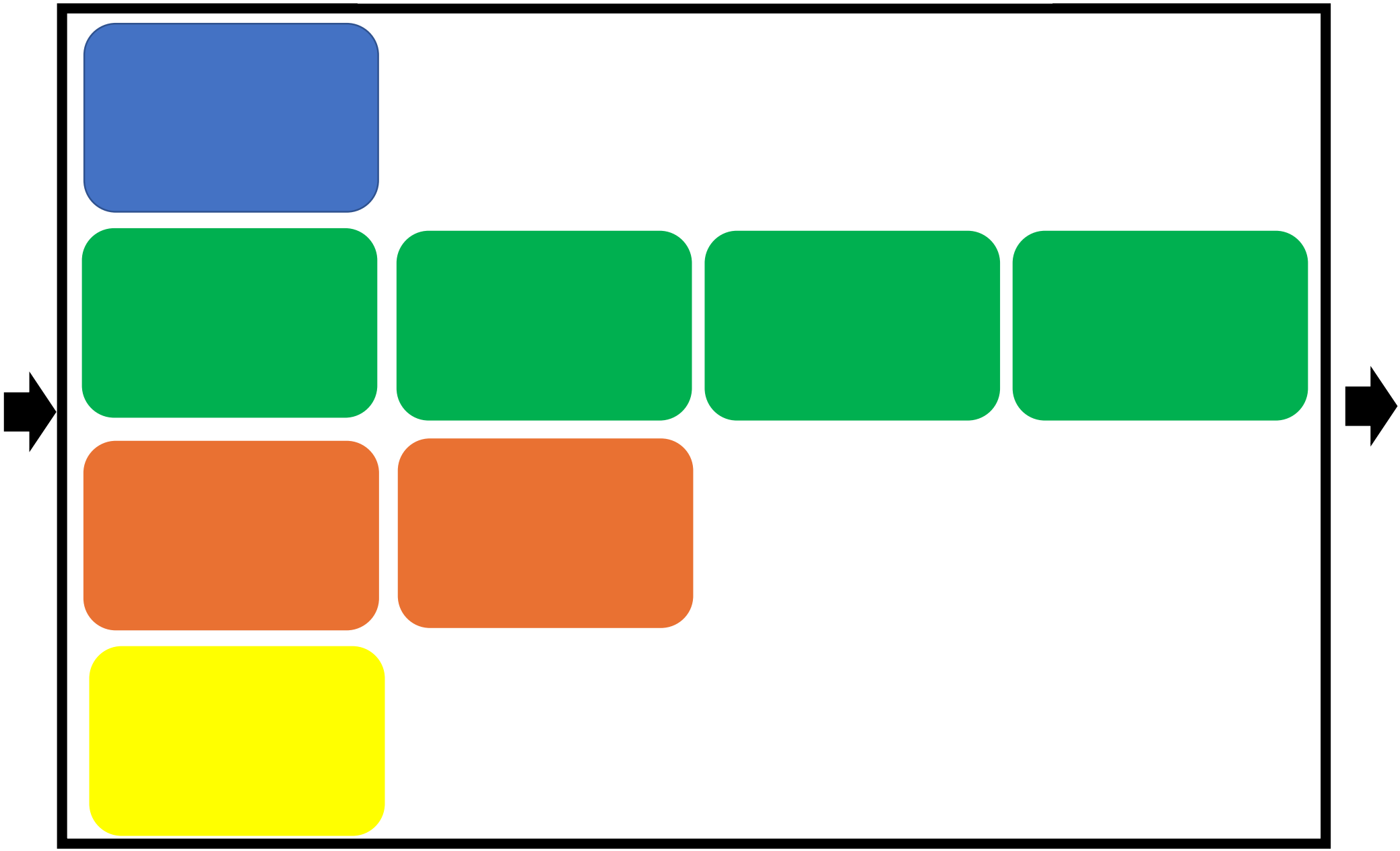
OPTION 2: New Machine 3



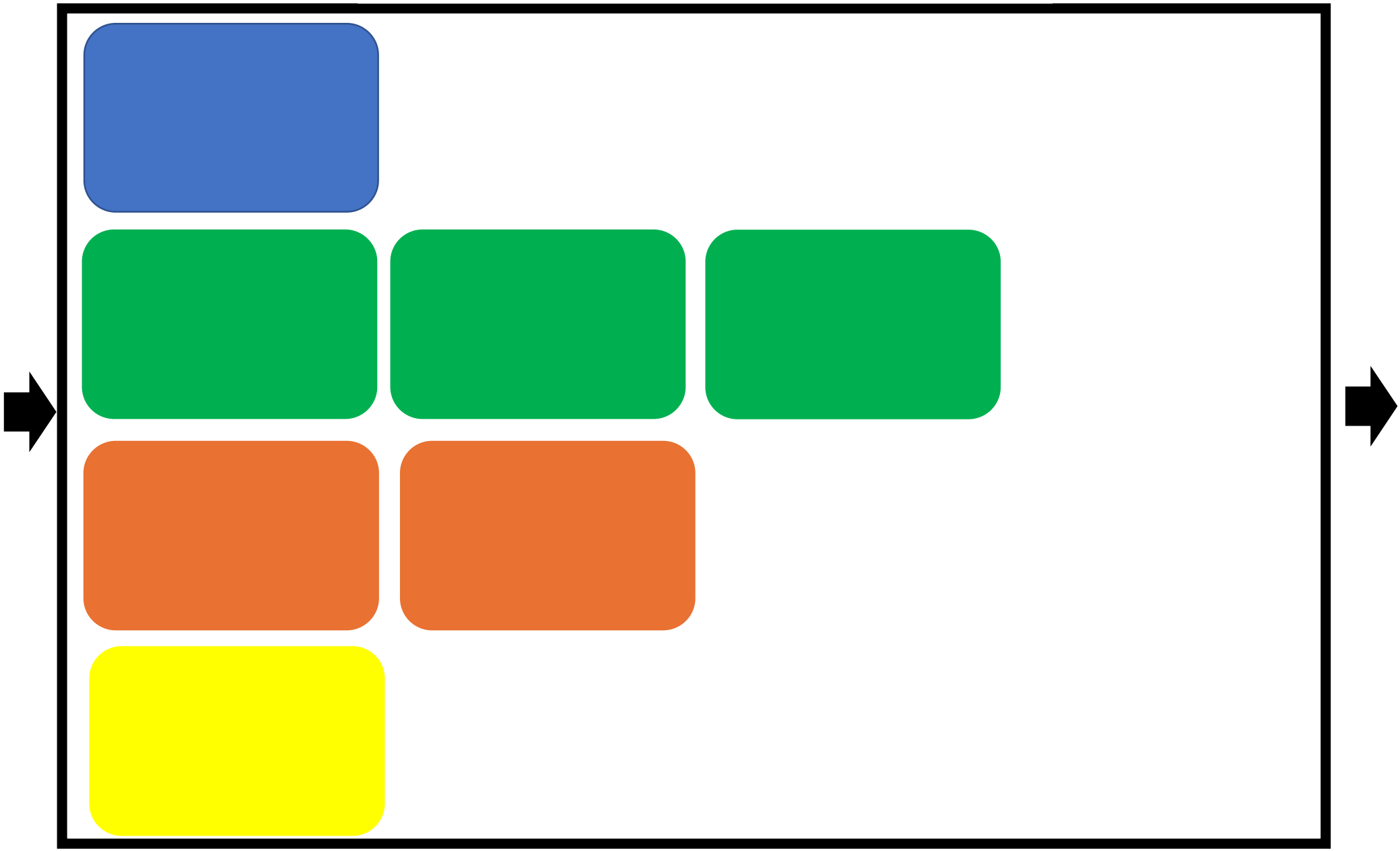
OPTION 2: New Machine 4



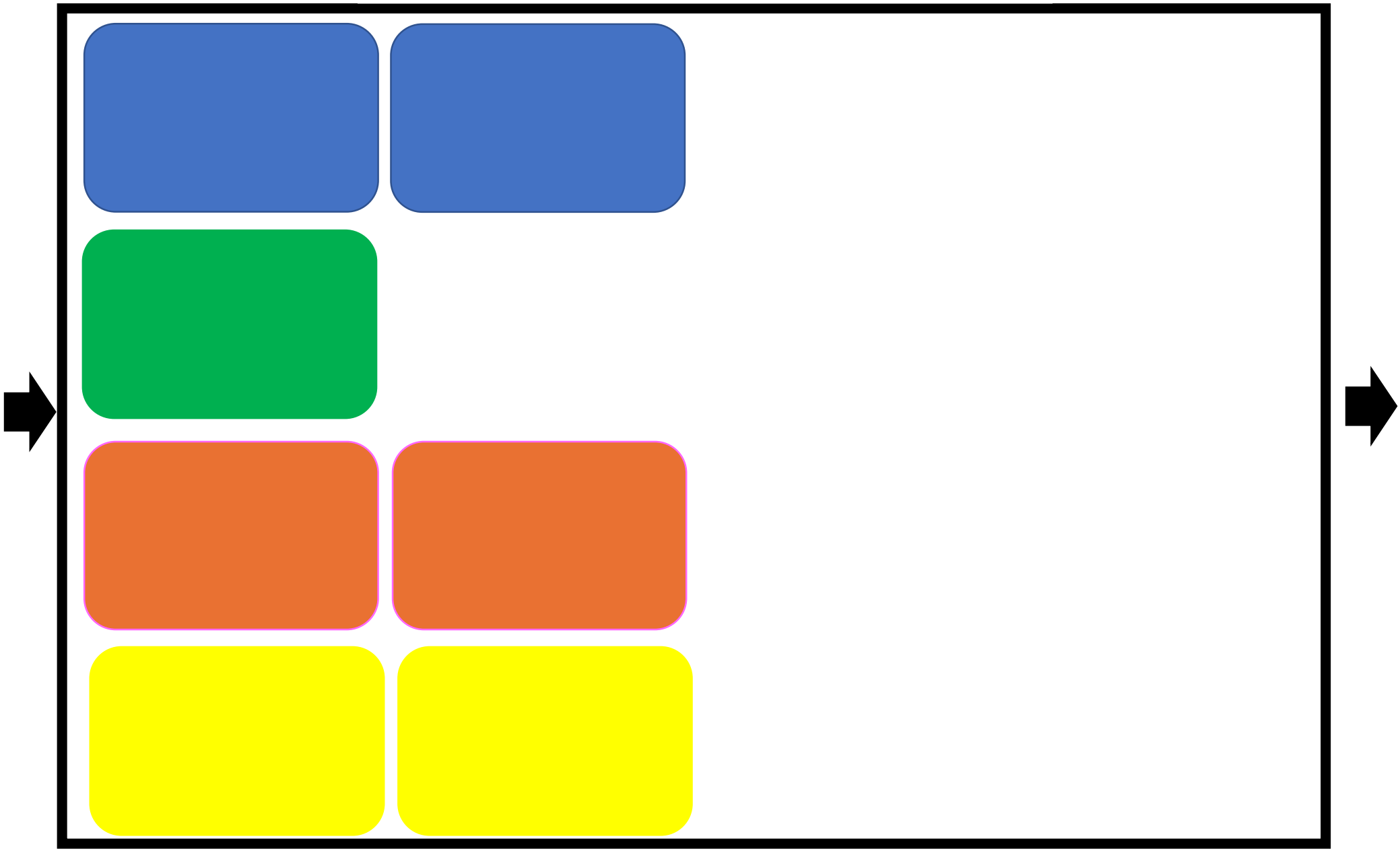
OPTION 3: New Machine 3



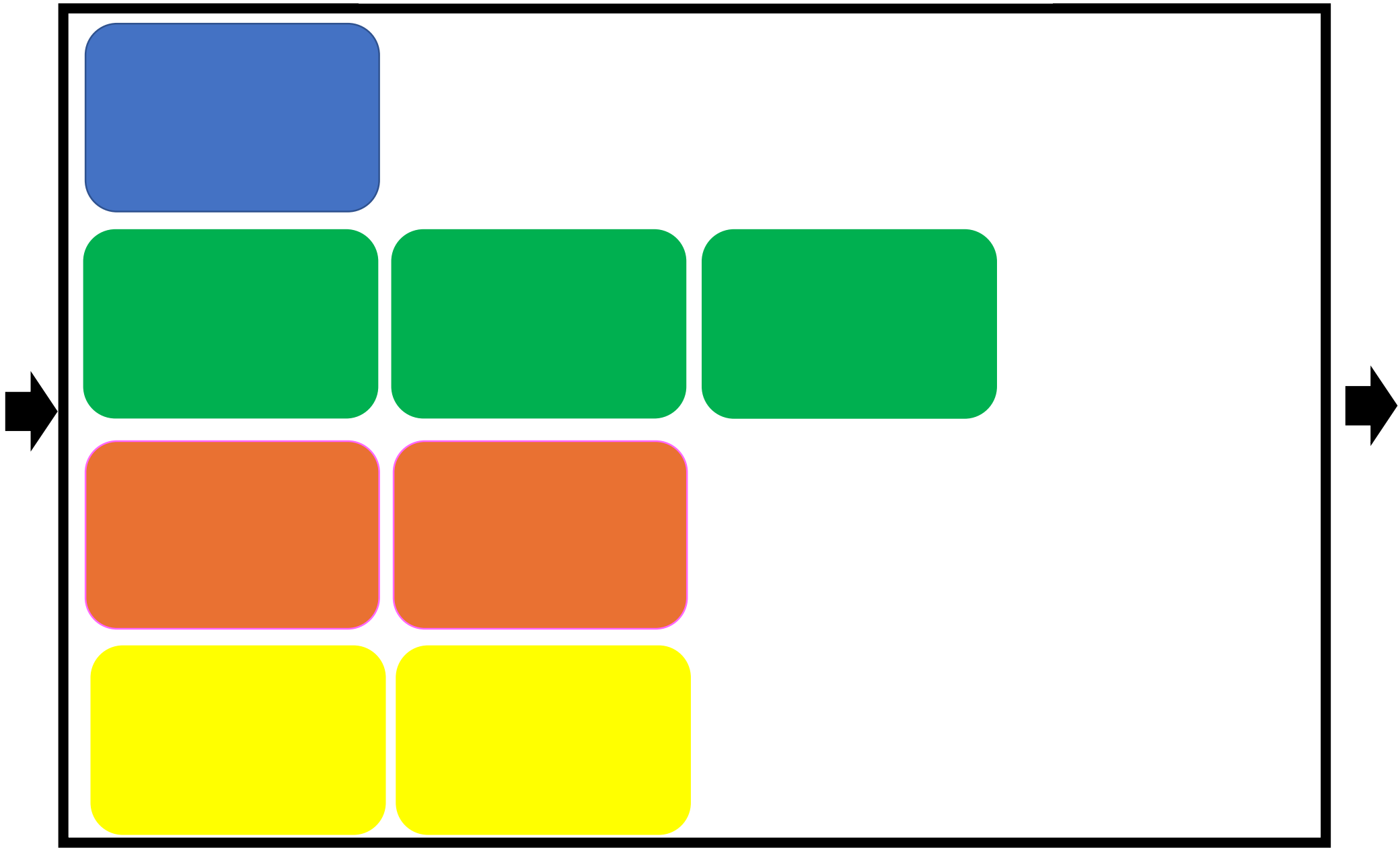
OPTION 3: New Machine 4



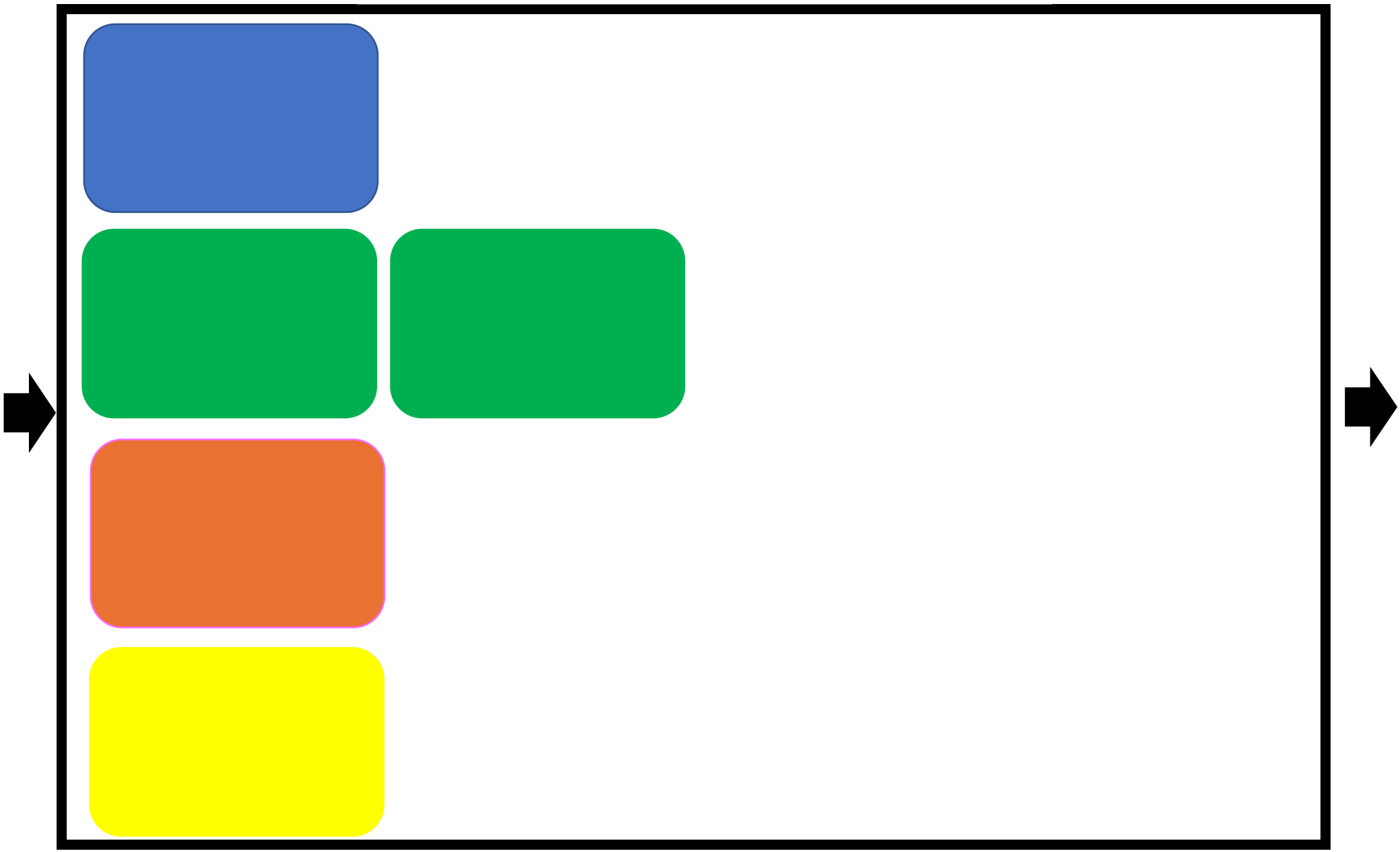
OPTION 4: New Machine 3



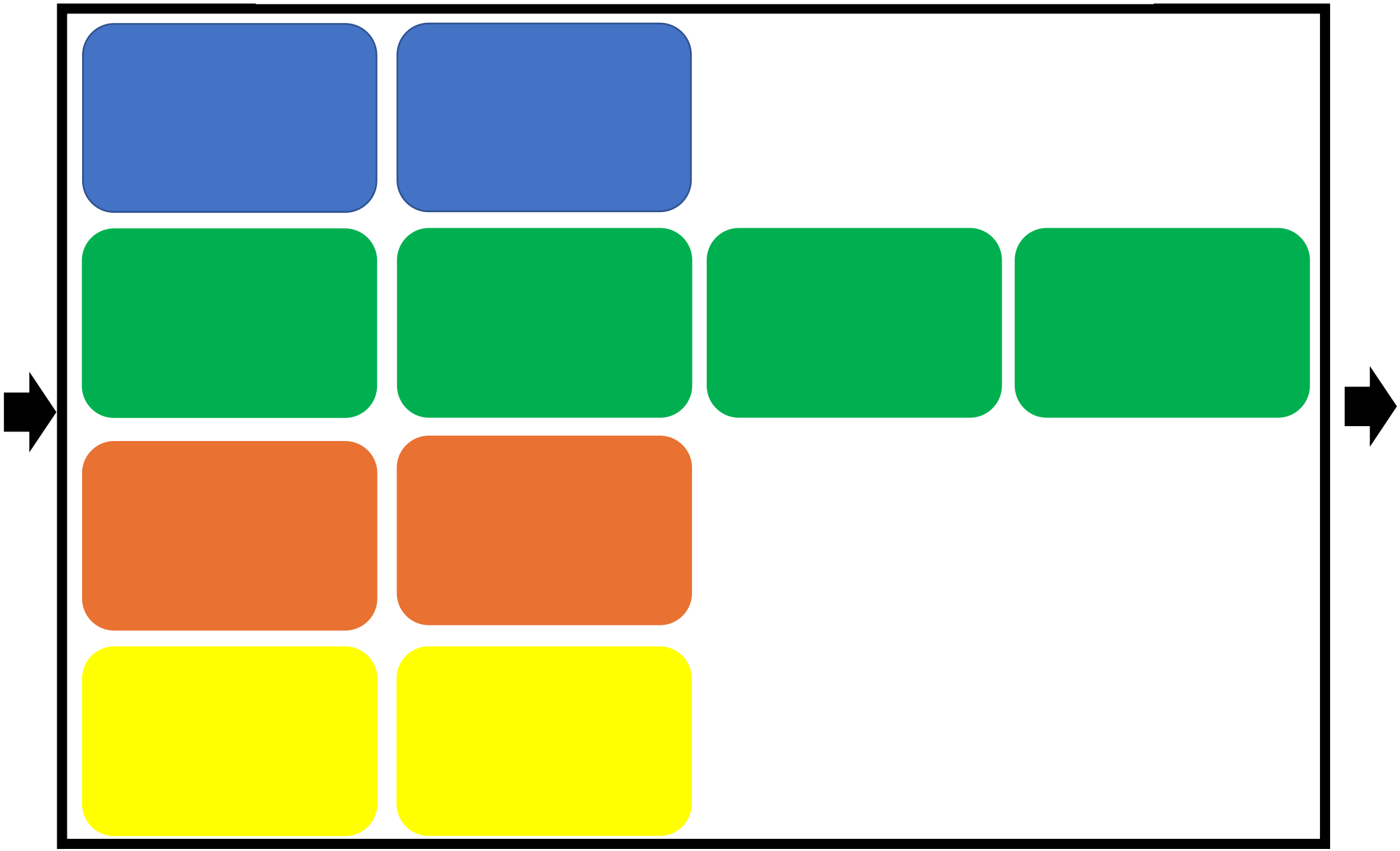
OPTION 4: New Machine 4



OPTION 5: New Machine 3



OPTION 6: New Parallel Machine 3



Paper Sheet of Module 1 to record the production order, quantities produced, and total profit

Schedule of production

Order of production	Toy car color
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	
13	
14	
15	
16	
17	
18	
19	
20	
21	
22	

Group: _____

Name 1: _____

Name 2: _____

Name 3: _____

Name 4: _____

Name 5: _____

Quantity Produced and Profit Table

Toy car	Unit margin	Quantity produced	Unit*Margin
Blue:			
Green:			
Orange:			
Yellow:			
Total profit:			

Paper Sheet of Module 2 to record the production order, quantities produced, and total profit

Schedule of production

Order of production	Toy car color
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	
13	
14	
15	
16	
17	
18	
19	
20	
21	
22	
23	
24	
25	
26	
27	

Group: _____

Name 1: _____

Name 2: _____

Name 3: _____

Name 4: _____

Name 5: _____

Quantity Produced and Profit Table

Toy car color	Unit margin	Quantity produced	Unit*Margin
Blue: Green: Orange: Yellow:			
Total weekly gross profit:			
Weekly cost of new capacity:			
Total weekly profit:			

Students' Guide
The Competitive Car Production Game: Module 1

The aim of this game is to:

(i) understand how to manage production processes;

(ii) understand the production limitations caused by a bottleneck in the process;

(iii) identify and optimize the use of a bottleneck and improve the overall system performance;

(iv) understand the concepts of TOC and LP;

(v) develop skills to mathematically model and solve production problems;

(vi) recognize the need for improved production scheduling.

PROBLEM DESCRIPTION

- **The toy car company produces and sells four types of toy cars:**
  - **blue racing car, green city car, pink convertible car, and yellow sports car.**

- **Toy cars are manufactured in a production system consisting of five workstations (WS) in sequence :**
  - **mold dye (WS 1), plastic injection molding (WS 2), painting (WS 3), assembly (WS 4), and packaging (WS 5);**
  - **a workstation consists of a single machine.**
  - **The Game Board is provided in the picture below, and explained in the text that follows.**

Figure 1: Game Board

OBJECTIVE:

- ***The company seeks to determine the optimal product mix to maximize its profit, subject to demand and capacity constraints over the planning horizon.***

Main tasks of each team:

- each team manages a production system presented on the board (see Figure 1);
- each student within a team is responsible for a specific workstation (WS);
- each team should determine how many and which type of toy cars to produce during the planning horizon in order to maximize the company's profit, considering the demand and capacity constraints, and the data discussed below and provided in Table 1.

Manufacturing process:

- The planning period T, defined as a series of rounds, is equal to 40.
- The production system consists of five workstations (WSs), denoted by j: the mold dye ($j = 1$), plastic injection molding ($j = 2$), painting ($j = 3$), assembly ($j = 4$), and packaging ($j = 5$).
- Each workstation in the production system consists of a single machine.
- In the production system, four different toy car types are produced (with the car type denoted by i): blue racing car ($i = 1$), green city car ($i = 2$), pink convertible car ($i = 3$), and yellow sports car ($i = 4$).
- Each machine can process only one toy car at a time, but is able to produce different types of cars.
- On the board (Figure 1), the number of squares of a certain color in a specific machine WS, represents the processing time for toy cars of that color (i) on that WS j, denoted by t_{ij}. For instance, a green toy car requires two periods (or rounds) of processing time on WS 1, so that $t_{21} = 2$.
- Production is carried out in sequence, i.e., a toy car should be produced first on the mold dye machine, then it requires plastic injection molding, afterwards painting, assembly, and finally packaging.
- The inventory of raw materials precedes the production system, while the inventory of finished goods follows it.
- Between two workstations there is a buffer/work in process (WIP) for toy cars that are waiting to be processed on the next workstation in case this machine is still occupied by the production of another toy car.
- Demand of toy car type i during T (d_i) is known and is placed in the inventory of raw materials in front of WS 1.
- If the company sells a toy car type i, it generates unit margin m_i.

Required data are presented in Table 1.

Toy car type i:	blue racing car ($i = 1$)	green city car ($i = 2$)	pink convertible car ($i = 3$)	yellow sports car ($i = 4$)
m_i	15	30	20	25
t_{i1}	1	2	1	3
t_{i2}	2	1	3	1
t_{i3}	2	4	2	2
t_{i4}	2	3	2	2
t_{i5}	1	3	1	1
d_i	4	7	6	5

Table 1: Data

Sequence of movements Figure 2 illustrates the movement of cars from the end of one round to the start of the next.

The main rules governing the sequence of movements are as follows:

1 A toy car advances by one square on a machine each round - from left to right (see Step 3 in Figure 2, where the blue car moves from the first square to the second square of WS 2).

2 If a machine on a WS is available, a toy car should be taken either from the inventory (see Step 1 in Figure 2 where a green car is taken to be produced on WS 1; and Step 6, where the yellow car is moved from the buffer between WS 4 & 5 to WS 5), or from a machine on the preceding WS if that station has completed its operation (see Step 4 where the yellow car moves from WS 3 to WS 4).

3 If a machine on a WS is available, and several toy cars are waiting in front of it (e.g. the pink and yellow cars before WS 5), the manager of that WS may decide which one to process next (in Step 6, the yellow car is selected).

4 If a machine has completed its operation on a toy car, the car can either be placed directly on the first square of the same color on the machine of the successor WS, provided that the WS is available (see Step 4), or moved to the inventory between these two WSs if the successor WS is occupied (see Step 2 where the blue car is moved from WS 1 to

the inventory between WS 1 and WS 2) or if the manager of that WS decides to process a different toy car from the buffer (as in Step 6).

5 Once a car completes the final production step at WS 5, it exits the production system, and is considered a finished product (see Step 7 where the green car that exists the production system).

6 To keep track of the decisions per team, at the end of each round, the student in charge of WS 5, should register the color of the toy car that exited the system (if any) in the table "Schedule of production".

7 At the end of the game, the team should count the number of each car type produced registered in the table "Schedule of production", calculate the total profit, and record these values in the "Quantity produced and profit" table.

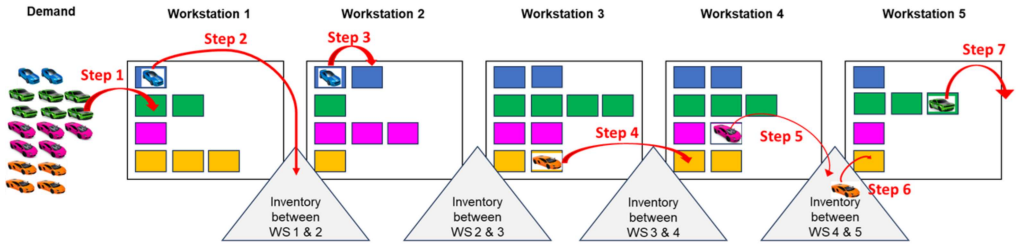


Figure 2: Car game movements illustration

Students' Guide
The Competitive Car Production Game: Module 2

The aim of this game is to:

(i) evaluate different options to increase capacity and determine the willingness to pay for these options;

(ii) evaluate the impact of competition for limited additional capacity and the overall market demand on company's profit and capacity and production decisions;

(iii) learn how to dynamically adjust operational decisions depending on competitors' decisions.

(iv) encourage collaborative decisions within a team.

Notes: Module 2 of the Game consists of two parts

- Part I: Competing for Capacity
- Part II: The Competitive Car Production Game

Part I of Module 2: Competing for Capacity

PROBLEM DESCRIPTION

- **Each toy car company has the possibility to acquire additional capacity to improve its performance.**
- **Different capacity investment options exist and are available on auction (see Figure 1 below):**
  - **Starting purchasing price of each option offered in the auction event is known.**

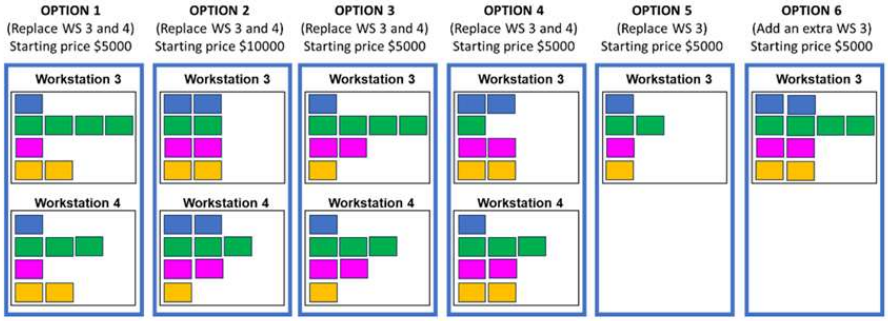


Figure 1 Capacity investment options offered in the auction

OBJECTIVE:

- ***The company can participate in the auction event to acquire additional capacity. If it chooses to participate, it should develop a bidding strategy for each available capacity option.***

Main tasks of each team:

- Since not all demand can be met using the existing production system (as shown in Module 1), the team may consider acquiring (a) new more powerful machine(s) through an auction event offering several capacity expansion options. The team should evaluate whether acquiring additional capacity is beneficial, and, if so, develop an appropriate bidding strategy for each available capacity option in the auction.
- During the auction event, the team will compete with other teams to acquire additional production capacity. This competition will involve placing progressively higher bids for a specific capacity option until no other team is willing to offer a higher price. In other words, the team with the highest bid price will secure the option.
- One team can at most invest in one capacity extension option.

Capacity expansion problem

- Several **capacity extension options** are offered at the auction, each with a different capacity configuration (i.e., the processing times of new machines and the number of workstations vary) and starting purchasing price (see Figure 1).
  - **Options 1-4** More efficient machines for WS 3 and WS4: These options involve replacing the old machines on WS 3 and WS 4 with new, faster ones. The new machines have reduced processing times for certain types of toy cars compared to the old machines.
  - **Option 5** Two times faster machine for WS 3: The team that acquires this option will need to replace the old machine WS 3 with this two times faster one.
  - **Option 6** New parallel machine for WS 3: The team that acquires this option will add a new machine in parallel to the existing one at WS 3.
  - **The starting purchasing price** of options is $ 5000, except for option 2, for which it is $10000. The new machines are aimed to be used for the next ten years. There are 50 working weeks in a year, with 40 working hours per week (i.e., when we play 40 rounds ($T = 40$) we consider this to represent one week of production, meaning that one round represents one hour).
- **Maximum willingness to pay** for an option: To determine an appropriate bidding strategy for the auction event, the team may evaluate the total profit generated under each capacity option. In particular, the team can solve the linear programming (LP) problem using the new capacity option and compare the resulting profit with the profit achieved under the existing production system (Module 1). This analysis can help the team identify the maximum amount it is willing to pay for specific capacity expansion options without incurring a reduction in profit relative to the Module 1 model.
- **Bidding** for each option in the auction event will follow the format of an English auction. During the auction event, bidders can place progressively higher bids for a specific capacity option until only one bidder remains - that is, the team with the highest bid price will secure the option.

Part II of Module 2: The Competitive Car Production Game

Upon acquiring new capacity in the auction event, the team will have to manage its production system (similar to Module 1), with the difference that all companies (teams) now operate under **competition for the overall market demand**.

- The total demand is equal to the sum of the demand of all teams in Module 1. However, the teams do not know what the other teams are producing, and demand will be realized at the end of the planning horizon T.

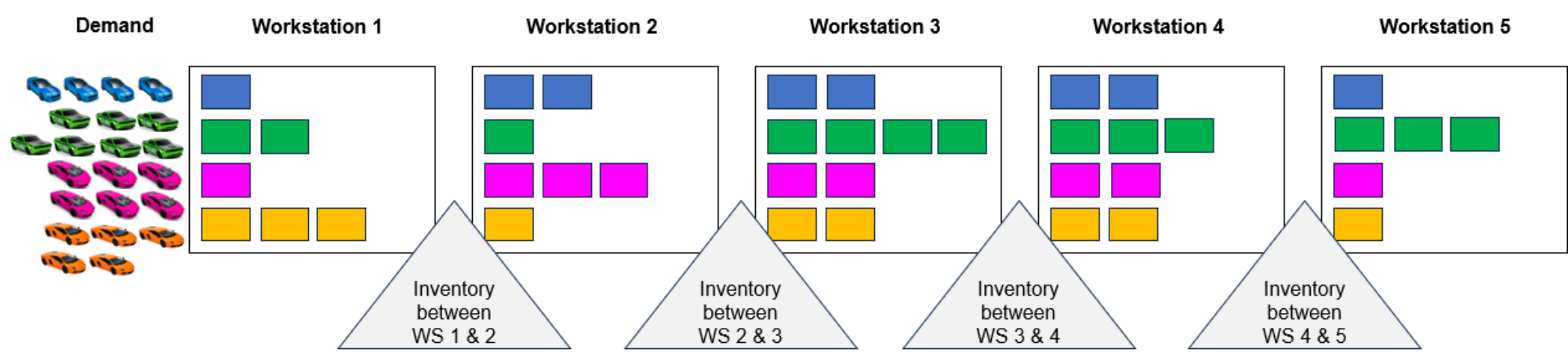
  If production exceeds demand for a certain type of toy car at the end of the game, the instructor will discard the excess according to the Last-In-First-Out (LIFO) basis - meaning the most recently produced piece will be discarded first. Furthermore, if multiple teams produce toy cars of the same color that need to be discarded in the same round, the discarded piece will be randomly selected from among those teams.

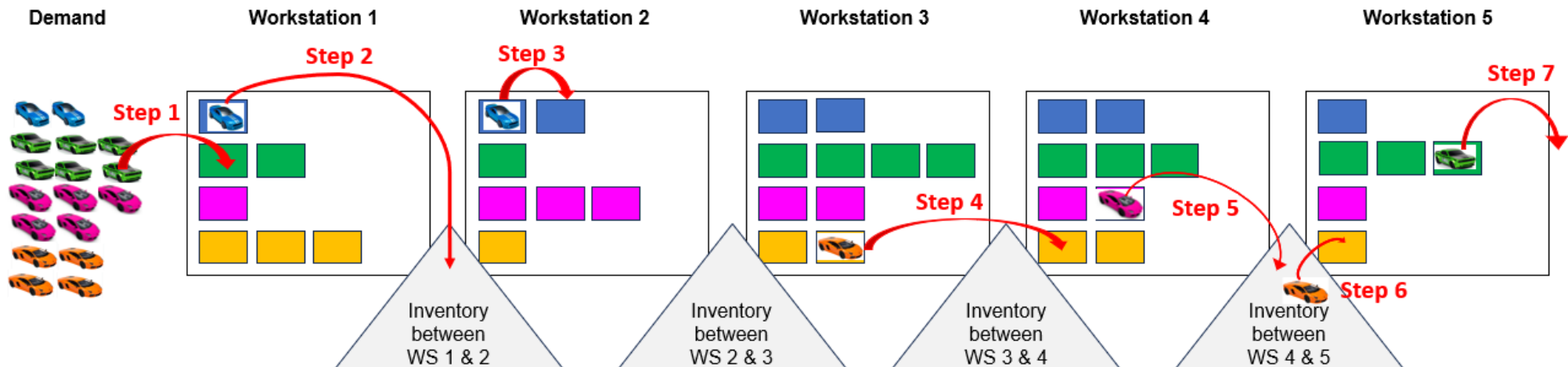
- Teams are allowed to adjust their production decisions in response to market competition in Module 2 of the game.

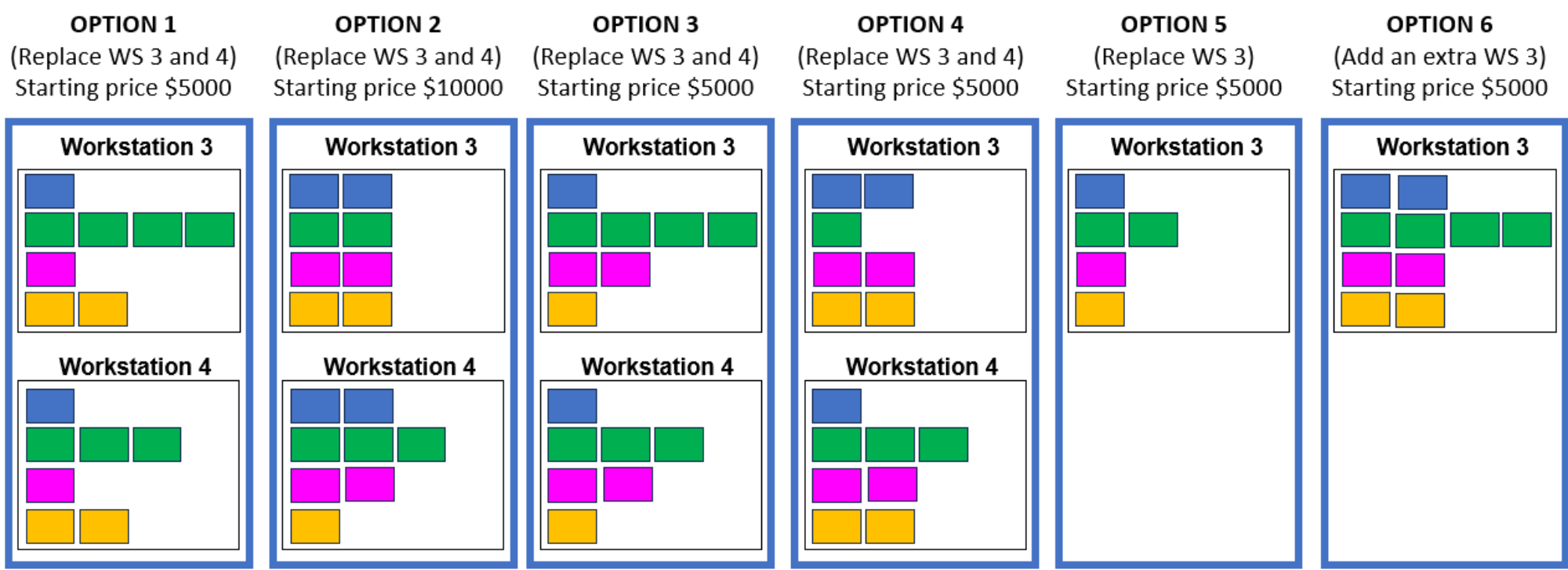
- The sequence of movements is the same as in Module 1.

- To keep track of the decisions per team, at the end of each round, as in Module 1, the teams should register their production in table "Schedule of production", calculate the total profit taking into account the weekly cost of new capacity, if acquired in auctions, and record these values in "Quantity produced and profit" table.

- At the end of the game, the instructor will reveal the winning team.


Demand
Workstation 1
Workstation 2
Workstation 3
Workstation 4
Workstation 5
Inventory between WS 1 & 2
Inventory between WS 2 & 3
Inventory between WS 3 & 4
Inventory between WS 4 & 5


Demand
Workstation 1
Workstation 2
Workstation 3
Workstation 4
Workstation 5
Step 1
Step 2
Step 3
Step 4
Step 5
Step 6
Step 7
Inventory between WS 1 & 2
Inventory between WS 2 & 3
Inventory between WS 3 & 4
Inventory between WS 4 & 5


OPTION 1
(Replace WS 3 and 4)
Starting price $5000
Workstation 3
Workstation 4
OPTION 2
(Replace WS 3 and 4)
Starting price $10000
Workstation 3
Workstation 4
OPTION 3
(Replace WS 3 and 4)
Starting price $5000
Workstation 3
Workstation 4
OPTION 4
(Replace WS 3 and 4)
Starting price $5000
Workstation 3
Workstation 4
OPTION 5
(Replace WS 3)
Starting price $5000
Workstation 3
OPTION 6
(Add an extra WS 3)
Starting price $5000
Workstation 3