Adjacency List and Distribution Classes

In [217]:
```
# Taken from https://www.programiz.com/dsa/graph-adjacency-list
# Adjascency List representation in Python

class AdjNode:
    def __init__(self, value):
        self.vertex = value
        self.next = None
        self.color = 0
        self.isSolo = False


class AdjacencyList:
    def __init__(self, num):
        self.V = num
        self.graph = [None] * self.V

    # Add edges
    def add_edge(self, s, d):
        # print("Adding edge", s, d)
        if(s == d): #check this shit it ran for infitity when I remove
            print("Solo node", d)
        else:
            node = AdjNode(d)
            node.next = self.graph[s]
            self.graph[s] = node

            node = AdjNode(s)
            node.next = self.graph[d]
            self.graph[d] = node


    def has_edge(self, s, d):
        node = self.graph[s]
        while node:
            if node.vertex == d:
                return True
            node = node.next
        return False

    # Print the graph
    def print_graph(self):
        for i in range(self.V):
            print("Vertex " + str(i) + ":", end="")
            temp = self.graph[i]
            while temp:
```

```
            while temp:
                print(" -> {}".format(temp.vertex), end="")
                temp = temp.next
            print(" \n")

    def get_node_degree(self, node):
        temp = self.graph[node]
        degree = 0
        while temp:
            degree += 1
            temp = temp.next
        return degree

    def get_all_unused(self):
        all_nodes = []
        for i in range(self.V):
            all_nodes.append(i)
        for i in self.graph:
            temp = i
            while temp:
                if temp.color == 0:
                    all_nodes.remove(temp.vertex)
                temp = temp.next
        return all_nodes

    def get_degree(self, vertex):
        temp = self.graph[vertex]
        degree = 0
        while temp:
            degree += 1
            temp = temp.next
        return degree

    def export_AdjList(self, filename):
        with open(filename, 'w') as f:
            for i in range(self.V):
                temp = self.graph[i]
                while temp:
                    f.write(str(i) + " " + str(temp.vertex) + "\n")
                    temp = temp.next
        f.close()

    def import_AdjList(self, filename):
        with open(filename, 'r') as f:
            for line in f:
                line = line.split()
                self.add_edge(int(line[0]), int(line[1]))
        f.close()
```

Graph Class

Includes functions for all of the orderings and the coloring of the graph

In [218]:
```
import random
import copy
import numpy as np
import gc

gc.disable() #disables garbage collection

class CreateGraph:
    def __init__(self, V = 5, E = 5, G = "COMPLETE", DIST = "UNIFORM")
        self.AdjList = AdjacencyList(V)
        self.vertices = V
        self.edges = E
        self.graph = G
        self.distribution = DIST
        self.currentEdges = 0
        self.degrees = [0] * self.vertices

    def populate(self):
        if self.graph == 'COMPLETE':
            for i in range(self.vertices):
                for j in range(i+1, self.vertices):
                    self.AdjList.add_edge(i, j)
                    self.currentEdges += 1

        elif self.graph == 'CYCLE':
            for i in range(self.vertices):
                self.AdjList.add_edge(i, (i+1)%self.vertices)
                self.currentEdges += 1

        elif self.graph == 'RANDOM':
            if self.distribution == 'UNIFORM':
                while self.currentEdges < self.edges and self.currentE
                    s = random.randint(0, self.vertices-1)
                    d = random.randint(0, self.vertices-1)
                    if self.AdjList.has_edge(s, d):
                        pass
                    elif s != d and not self.AdjList.has_edge(s, d):
                        self.AdjList.add_edge(s, d)
                        self.currentEdges += 1

            elif self.distribution == 'SKEWED':
                while self.currentEdges < self.edges and self.currentE
                    s = min(random.randint(0, self.vertices-1), random
```

```
                    d = min(random.randint(0, self.vertices-1), random
                    if s == d or self.AdjList.has_edge(s, d):
                        pass
                    else:
                        self.AdjList.add_edge(s, d)
                        self.currentEdges += 1
            elif self.distribution == 'CUSTOM':
                while self.currentEdges < self.edges and self.currentE
                    s = min(random.randint(0, self.vertices-1), random
                    d = max(random.randint(0, self.vertices-1), random
                    if s == d or self.AdjList.has_edge(s, d):
                        pass
                    else:
                        self.AdjList.add_edge(s, d)
                        self.currentEdges += 1

    #Eric Based
    def colorGraph(self, ordering):
        G = copy.deepcopy(self.AdjList)
        colors = [0] * self.vertices
        for i in range(len(ordering)):
            vertex = ordering[i]
            if G.graph[vertex] == None:
                continue
            else:
                temp = G.graph[vertex]
                while temp:
                    if colors[temp.vertex] == colors[vertex]:
                        colors[vertex] += 1
                        temp = G.graph[vertex]
                    else:
                        temp = temp.next
            self.AdjList.graph[vertex].color = colors[vertex]
        return colors

    def getDegrees(self):
        degrees = [0] * self.vertices
        for i in range(self.vertices):
            temp = self.AdjList.graph[i]
            while temp:
                degrees[i] += 1
                temp = temp.next
        self.degrees = degrees
        return degrees

    def getSmallestLastVertexOrdering(self, degrees):
        remainingDegrees = copy.deepcopy(degrees)
        ordering = []
        while len(ordering) < self.vertices:
            minDegree = self.vertices + 1
            minVertex = -1
```

```
            minVertex = -1
            for i in range(self.vertices):
                if remainingDegrees[i] < minDegree and i not in orderi
                    minDegree = remainingDegrees[i]
                    minVertex = i
            ordering.append(minVertex)
            temp = self.AdjList.graph[minVertex]
            while temp:
                remainingDegrees[temp.vertex] -= 1
                temp = temp.next
        ordering.reverse()
        return ordering

    def getSmallestOriginalDegreeOrdering(self, degrees):
        remainingDegrees = copy.deepcopy(degrees)
        ordering = []
        for i in range(self.vertices):
            maxDegree = -1
            maxVertex = -1
            for i in range(self.vertices):
                if remainingDegrees[i] > maxDegree:
                    maxDegree = remainingDegrees[i]
                    maxVertex = i
            remainingDegrees[maxVertex] = -1
            ordering.append(maxVertex)
        ordering.reverse()
        return ordering

    def getLargestOriginalDegreeOrdering(self, degrees):
        remainingDegrees = copy.deepcopy(degrees)
        ordering = []
        for i in range(self.vertices):
            maxDegree = -1
            maxVertex = -1
            for i in range(self.vertices):
                if remainingDegrees[i] > maxDegree:
                    maxDegree = remainingDegrees[i]
                    maxVertex = i
            remainingDegrees[maxVertex] = -1
            ordering.append(maxVertex)
        return ordering

    def getUniformRandomOrdering(self):
        ordering = []
        for i in range(self.vertices):
            ordering.append(i)
        random.shuffle(ordering)
        return ordering

    def getMinimumWidthOrdering(self, degrees):
        G = copy.deepcopy(self.AdjList)
```

```
        remainingDegrees = copy.deepcopy(degrees)
        widthDegrees = [0] * self.vertices
        ordering = []
        for i in range(self.vertices):
            #fills out width degrees for given state
            for j in range(self.vertices):
                temp = G.graph[j]
                neighbor_degrees = []
                # print(temp)
                while temp:
                    temp = temp.next
                    if temp:
                        neighbor_degrees.append(remainingDegrees[temp.
                #take the maximum value of the array neighbor_degrees
                max_neighbor_degree = -1
                for k in range(len(neighbor_degrees)):
                    if k == 0:
                        max_neighbor_degree = neighbor_degrees[k]
                    else:
                        max_neighbor_degree = max(max_neighbor_degree,
                widthDegrees[j] = max(widthDegrees[j], max_neighbor_de

            minDegree = self.vertices + 1
            minVertex = -1
            for i in range(self.vertices):
                if remainingDegrees[i] < minDegree and i not in orderi
                    minDegree = remainingDegrees[i]
                    minVertex = i
            ordering.append(minVertex)
            temp = self.AdjList.graph[minVertex]
            while temp:
                remainingDegrees[temp.vertex] -= 1
                temp = temp.next
        # ordering.reverse()
        return ordering


    def getNumberOfColors(self, colors):
        maxColor = -1
        for i in range(self.vertices):
            maxColor = max(maxColor, colors[i])
        return maxColor + 1

    def print_AdjList(self):
        self.AdjList.print_graph()
```

Visualizing Outputs

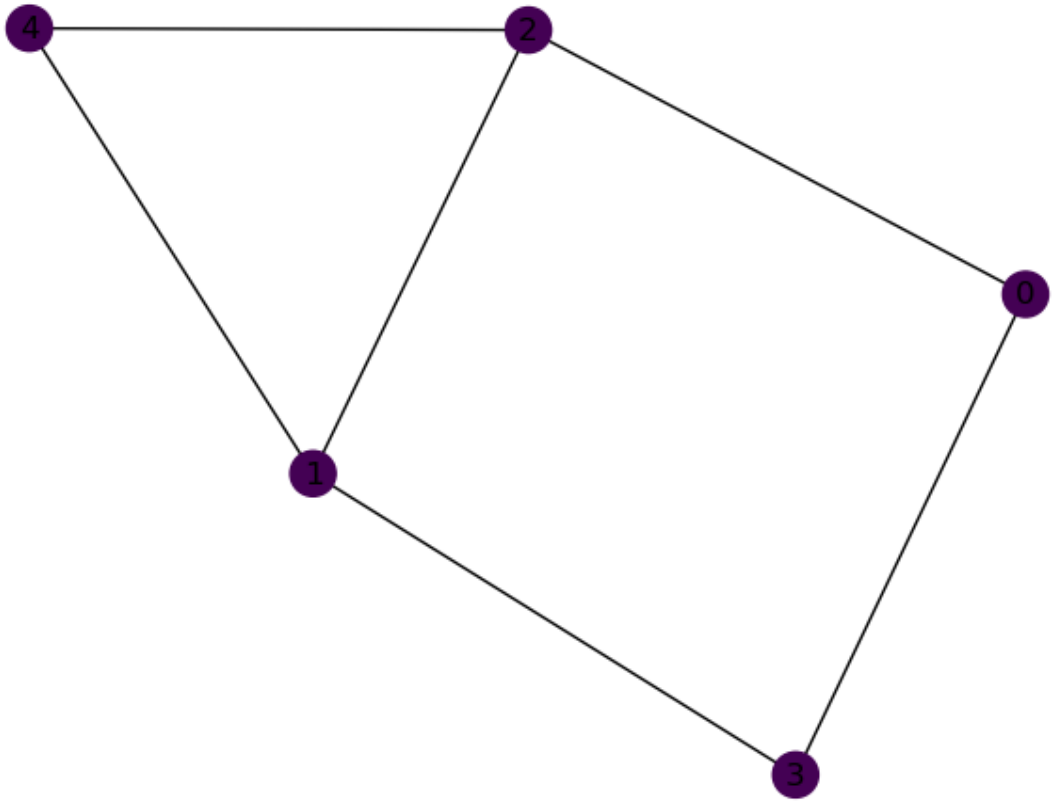
In [219]:
```
import networkx as nx
import matplotlib.pyplot as plt
import numpy as np
```

In [220]:
```
def visualize(graph):
    G = nx.Graph()
    colors = [0] * graph.V
    for i in range(graph.V):
        if(graph.graph[i] == None):
            continue
        else:
            colors[i] = graph.graph[i].color
    for i in range(graph.V):
        temp = graph.graph[i]
        while temp:
            G.add_edge(i, temp.vertex)
            temp = temp.next

    for i in range(graph.V):
        if graph.get_degree(i) == 0:
            G.add_node(i)
    nx.draw(G, with_labels=True, node_color=colors)
    plt.show()

def visualize_colors(org):
    G = nx.Graph()
    graph = copy.deepcopy(org)
    colors = []
    for i in range(graph.V):
        if(graph.graph[i] == None):
            colors.append(0)
        else:
            colors.append(graph.graph[i].color)

    for i in range(graph.V):
        temp = graph.graph[i]
        while temp:
            G.add_edge(i, temp.vertex)
            temp = temp.next

    #add isolated nodes
    for i in range(graph.V):
        if graph.get_degree(i) == 0:
            G.add_node(i)

    color_map = []
    for node in G:
        if(graph.graph[node] == None):
            color_map.append(0)
```

```
        else:
            color_map.append(graph.graph[node].color)


    nx.draw(G, node_color=color_map, with_labels=True)
    plt.show()
```

In [221]:
```
number_of_vertices = 5
number_of_edges = 6
Graph_type = 'RANDOM'
Random_Type = 'UNIFORM'
outGraph = CreateGraph(number_of_vertices, number_of_edges, Graph_type
outGraph.populate()

# export the Adjlist of testGraph to a file
outGraph.AdjList.export_AdjList('testGraph.txt')
```

In [222]:
```
inGraph = CreateGraph()
#reads in from text file to populate the AdjList of the graph
inGraph.AdjList.import_AdjList('testGraph.txt')

visualize(inGraph.AdjList)
```



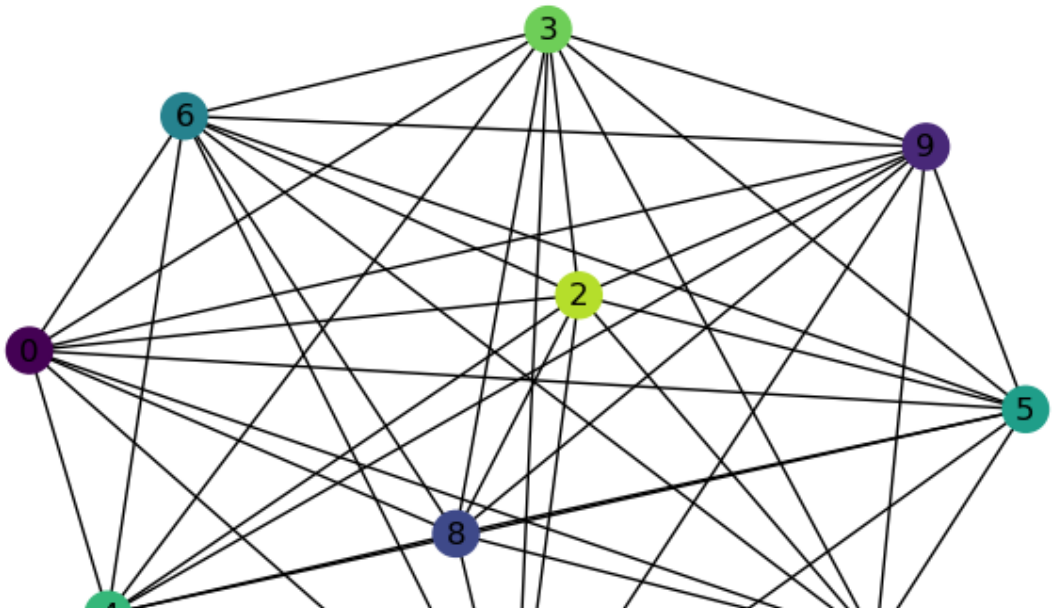
Implimenting Graph Coloring

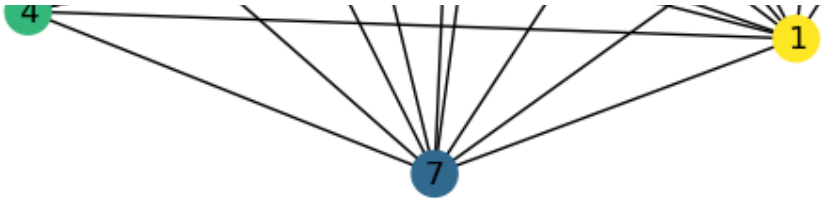
Shows an assortment of sample Implimentations of different graphs and different ordering algorithms applied to them

In [223]:
```

```

```
# Create graph and edges
print("Complete Graph")
graphComplete = CreateGraph(10, 10, 'COMPLETE', 'UNIFORM')
graphComplete.populate()
degrees = []
degrees = graphComplete.getDegrees()
ordering = graphComplete.getSmallestLastVertexOrdering(degrees)
print("Smallest Last Vertex Ordering: ")
print(ordering)
coloring = graphComplete.colorGraph(ordering)
print("Coloring: ", coloring)
print("Number of Colors: ", graphComplete.getNumberOfColors(coloring))
for i in range(coloring.__len__()):
    print("Vertex", i, " is colored ", coloring[i])
visualize_colors(graphComplete.AdjList)
```

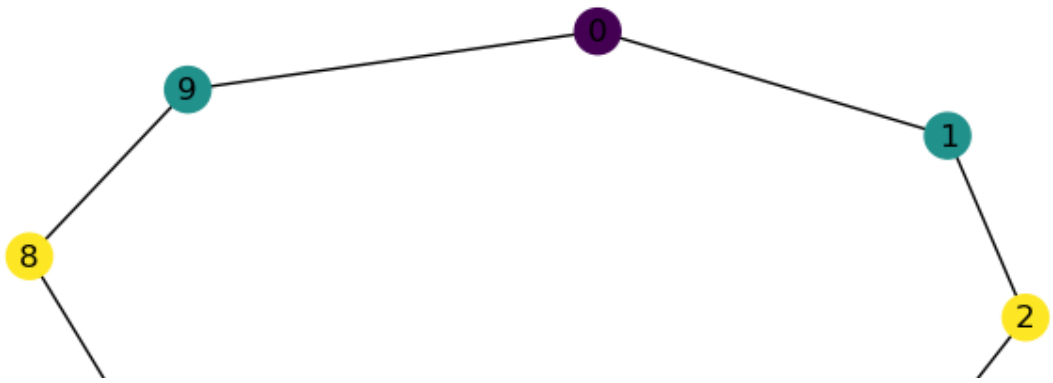
```
Complete Graph
Smallest Last Vertex Ordering:
[9, 8, 7, 6, 5, 4, 3, 2, 1, 0]
Coloring:  [0, 9, 8, 7, 6, 5, 4, 3, 2, 1]
Number of Colors:  10
Vertex 0  is colored  0
Vertex 1  is colored  9
Vertex 2  is colored  8
Vertex 3  is colored  7
Vertex 4  is colored  6
Vertex 5  is colored  5
Vertex 6  is colored  4
Vertex 7  is colored  3
Vertex 8  is colored  2
Vertex 9  is colored  1
```

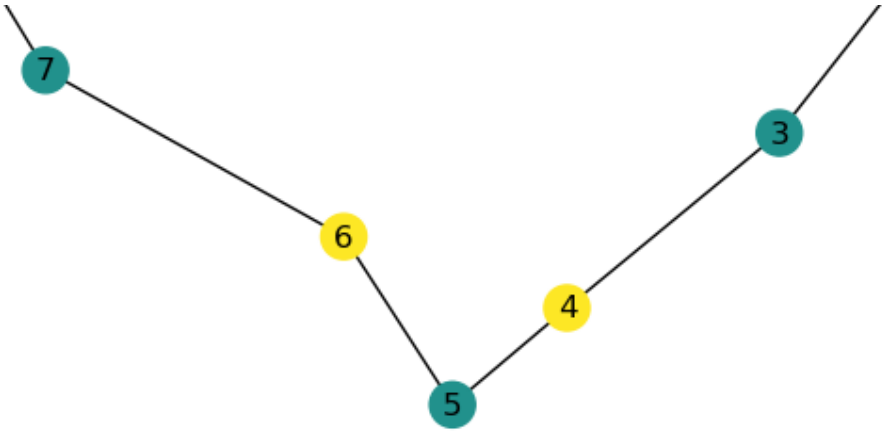




In [224]:
```
print("Cycle Graph", '\n')
graphCycle = CreateGraph(10, 3, 'CYCLE', 'UNIFORM')
graphCycle.populate()
degrees = []
degrees = graphCycle.getDegrees()
ordering = graphCycle.getSmallestLastVertexOrdering(degrees)
print("Smallest Last Vertex Ordering:", ordering)
coloring = graphCycle.colorGraph(ordering)
print("Colors:", coloring)
print("Number of Colors: ", graphCycle.getNumberOfColors(coloring))
for i in range(coloring.__len__()):
    print("Vertex", i, " is colored ", coloring[i])
visualize_colors(graphCycle.AdjList)
```

```
Cycle Graph

Smallest Last Vertex Ordering: [9, 8, 7, 6, 5, 4, 3, 2, 1, 0]
Colors: [0, 1, 2, 1, 2, 1, 2, 1, 2, 1]
Number of Colors:  3
Vertex 0  is colored  0
Vertex 1  is colored  1
Vertex 2  is colored  2
Vertex 3  is colored  1
Vertex 4  is colored  2
Vertex 5  is colored  1
Vertex 6  is colored  2
Vertex 7  is colored  1
Vertex 8  is colored  2
Vertex 9  is colored  1
```





In [261]:

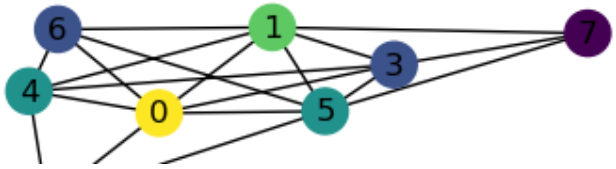
```
print("Random Uniform Graph", '\n')
graphRandUni = CreateGraph(6, 7, 'RANDOM', 'UNIFORM')
graphRandUni.populate()
degrees = []
degrees = graphRandUni.getDegrees()
ordering = graphRandUni.getSmallestLastVertexOrdering(degrees)
print("Degrees:", degrees)
print("Smallest Last Vertex Ordering: ", ordering)
coloring = graphRandUni.colorGraph(ordering)
print("Smallest Last Vertex Coloring", coloring)
print("Number of Colors: ", graphRandUni.getNumberOfColors(coloring))
visualize_colors(graphRandUni.AdjList)

print("Degrees:", degrees)
ordering = graphRandUni.getSmallestOriginalDegreeOrdering(degrees)
print("Smallest Original Degree Ordering: ", ordering)
coloring = graphRandUni.colorGraph(ordering)
print("Smallest Original Degree Coloring", coloring)
print("Number of Colors: ", graphRandUni.getNumberOfColors(coloring))
visualize_colors(graphRandUni.AdjList)

print("Degrees:", degrees)
ordering = graphRandUni.getLargestOriginalDegreeOrdering(degrees)
print("Largest Original Degree Ordering: ", ordering)
coloring = graphRandUni.colorGraph(ordering)
print("Largest Original Degree Coloring", coloring)
print("Number of Colors: ", graphRandUni.getNumberOfColors(coloring))
visualize_colors(graphRandUni.AdjList)

ordering = graphRandUni.getUniformRandomOrdering()
print("Uniform Random Ordering: ", ordering)
coloring = graphRandUni.colorGraph(ordering)
print("Uniform Random Coloring", coloring)
print("Number of Colors: ", graphRandUni.getNumberOfColors(coloring))
visualize_colors(graphRandUni.AdjList)

ordering = graphRandUni.getMinimumWidthOrdering(degrees)
print("Minimum Width ordering: ", ordering)
coloring = graphRandUni.colorGraph(ordering)
print("Minimum Width coloring", coloring)
print("Number of Colors: ", graphRandUni.getNumberOfColors(coloring))
visualize_colors(graphRandUni.AdjList)
```

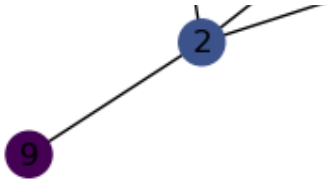
```
Random Uniform Graph

Degrees: [1, 3, 4, 1, 2, 3]
Smallest Last Vertex Ordering:  [5, 4, 2, 1, 3, 0]
```

```
Smallest Last Vertex Coloring [0, 2, 3, 0, 2, 1]
Number of Colors:  4
```

In [226]:
```
print("Random Skewed Graph", '\n')
graphRandSkew = CreateGraph(10, 20, 'RANDOM', 'SKEWED')
graphRandSkew.populate()
degrees = graphRandSkew.getDegrees()
ordering = graphRandSkew.getSmallestLastVertexOrdering(degrees)
print("Smallest Last Vertex Ordering: ")
print(ordering)
coloring = graphRandSkew.colorGraph(ordering)
print(coloring)
for i in range(coloring.__len__()):
    print("Vertex", i, " is colored ", coloring[i])
visualize_colors(graphRandSkew.AdjList)
```

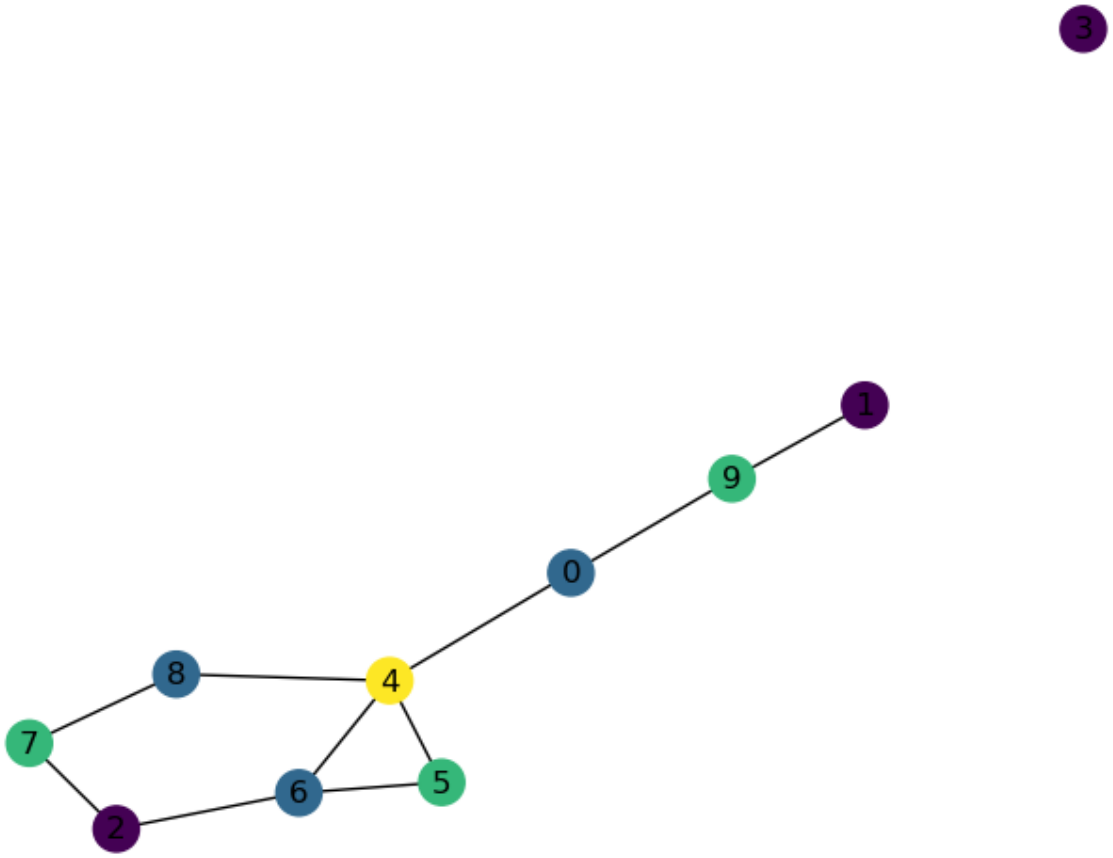
```
Random Skewed Graph

Smallest Last Vertex Ordering:
[6, 5, 1, 0, 4, 3, 7, 2, 9, 8]
[4, 3, 1, 1, 2, 2, 1, 0, 0, 0]
Vertex 0  is colored  4
Vertex 1  is colored  3
Vertex 2  is colored  1
Vertex 3  is colored  1
Vertex 4  is colored  2
Vertex 5  is colored  2
Vertex 6  is colored  1
Vertex 7  is colored  0
Vertex 8  is colored  0
Vertex 9  is colored  0
```





In [227]:
```
print("Random Custom Graph", '\n')
graphRandCust = CreateGraph(10, 10, 'RANDOM', 'CUSTOM')
graphRandCust.populate()
degrees = []
degrees = graphRandCust.getDegrees()
ordering = graphRandCust.getSmallestLastVertexOrdering(degrees)
print("Smallest Last Vertex Ordering: ")
print(ordering)
coloring = graphRandCust.colorGraph(ordering)
print(coloring)
for i in range(coloring.__len__()):
    print("Vertex", i, " is colored ", coloring[i])
visualize_colors(graphRandCust.AdjList)
```

```
Random Custom Graph

Smallest Last Vertex Ordering:
[6, 5, 4, 8, 7, 2, 0, 9, 1, 3]
[1, 0, 0, 0, 3, 2, 1, 2, 1, 2]
Vertex 0  is colored  1
Vertex 1  is colored  0
Vertex 2  is colored  0
Vertex 3  is colored  0
Vertex 4  is colored  3
Vertex 5  is colored  2
Vertex 6  is colored  1
Vertex 7  is colored  2
Vertex 8  is colored  1
Vertex 9  is colored  2
```



Graph Creation Timing

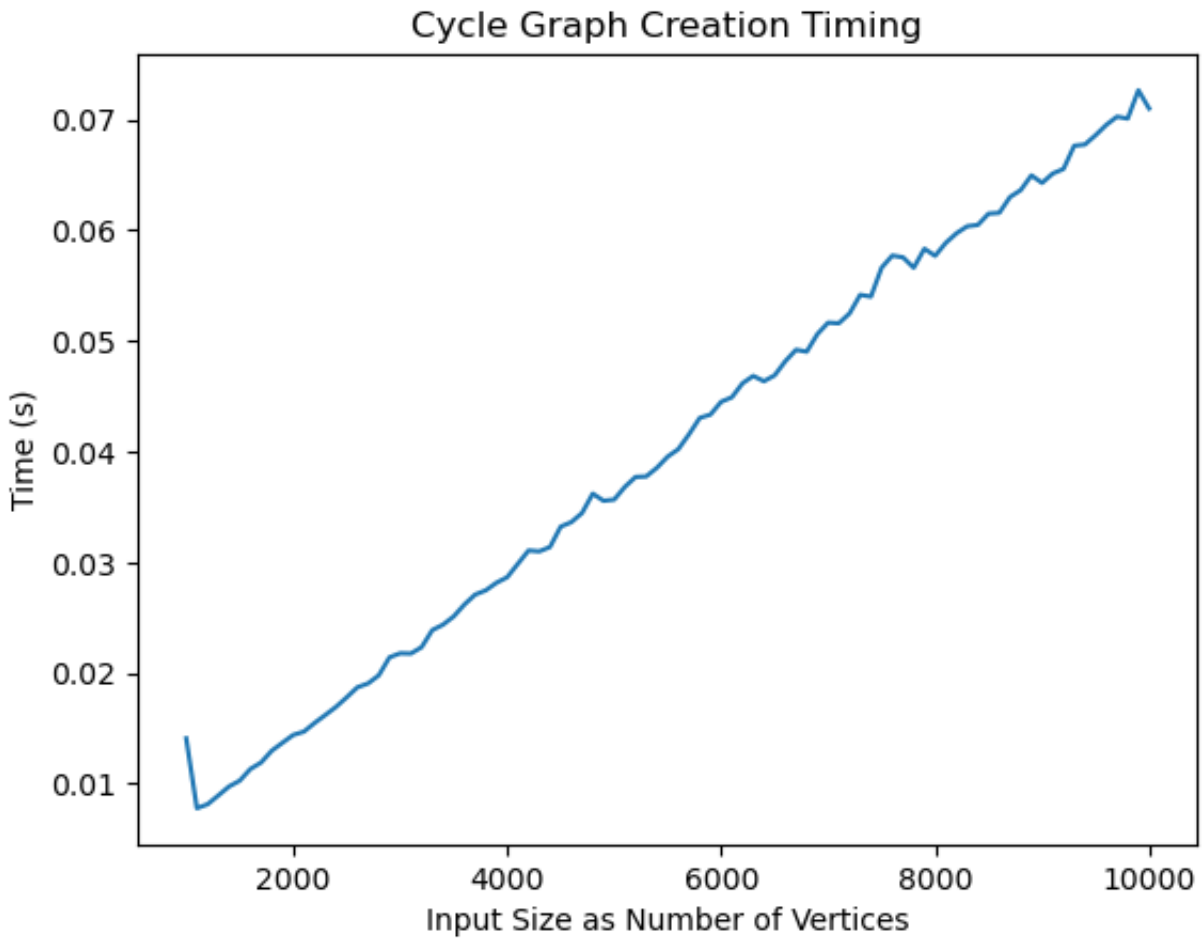
In [228]:
```
# timing graph creation
import time
import pandas as pd
import matplotlib.pyplot as plt
import numpy as np
```

In [229]:
```

```

```
print("Cycle Graph")
input_sizes_cycle = [i for i in range(1000, 10001, 100)]
graph_creation_times_average = [0] * input_sizes_cycle.__len__()
for j in range(50):
    graph_creation_times = []
    for i in input_sizes_cycle:
        time_start = 0
        time_start = time.time()
        graph = CreateGraph(i, 100, 'CYCLE', 'UNIFORM')
        graph.populate()
        time_end = time.time()
        graph_creation_times.append(time_end - time_start)

    for x in range(graph_creation_times.__len__()):
        graph_creation_times_average[x] += graph_creation_times[x]

for x in range(graph_creation_times_average.__len__()):
    graph_creation_times_average[x] /= 10

df = pd.DataFrame(columns = ['Input Size', 'Time'])
#put every 10th value in the input_sizes_random_uni list into the data
df['Input Size'] = input_sizes_cycle[::10]
df['Time'] = graph_creation_times_average[::10]
display(df)

plt.plot(input_sizes_cycle, graph_creation_times_average)
plt.title('Cycle Graph Creation Timing')
plt.xlabel('Input Size as Number of Vertices')
plt.ylabel('Time (s)')
plt.show()
```

Cycle Graph

	Input Size	Time
0	1000	0.014103
1	2000	0.014412
2	3000	0.021787
3	4000	0.028652
4	5000	0.035661
5	6000	0.044493
6	7000	0.051639
7	8000	0.057674
8	9000	0.064258
9	10000	0.070975

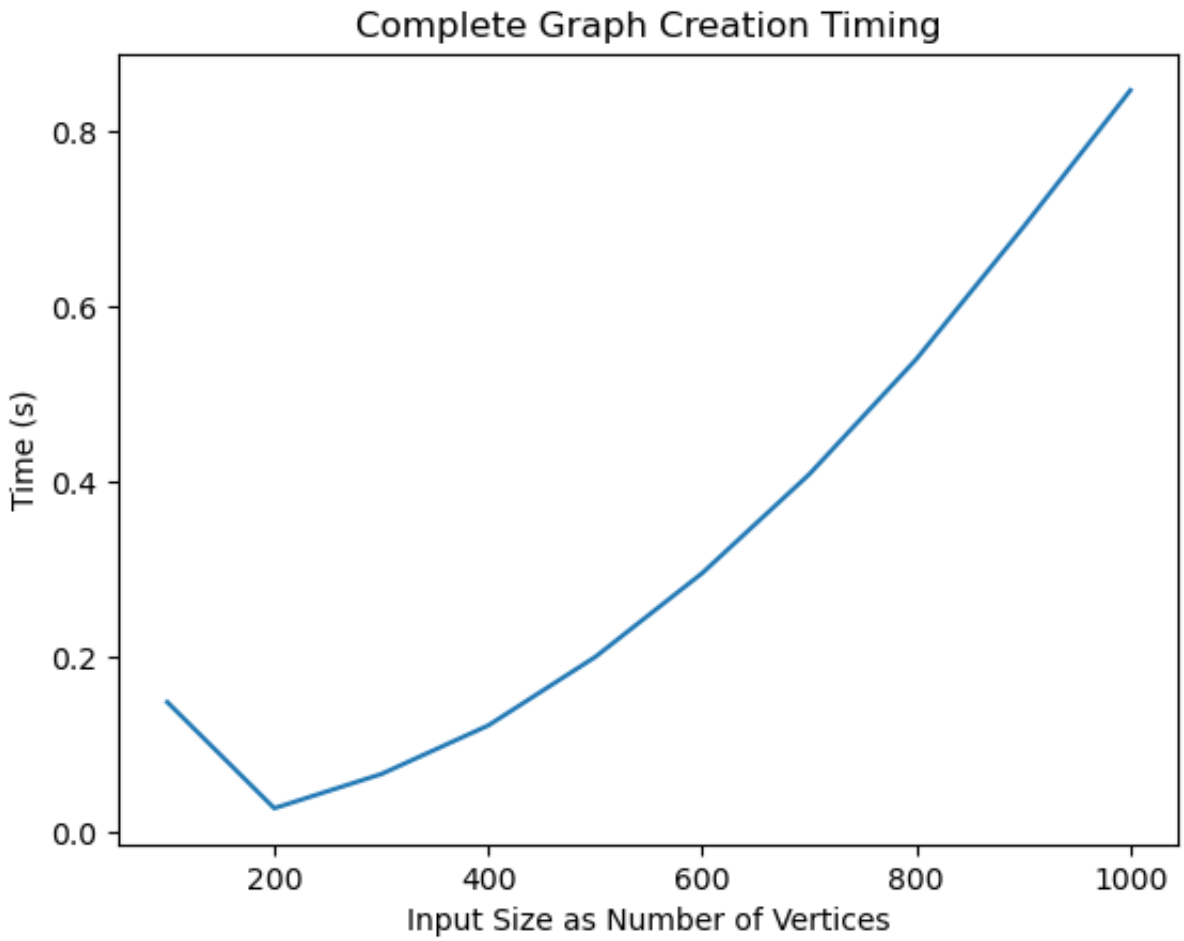

Cycle Graph Creation Timing
Time (s)
0.07
0.06
0.05
0.04
0.03
0.02
0.01
2000
4000
6000
8000
10000
Input Size as Number of Vertices

In [230]:

```
print("Complete Graph")
input_sizes_complete = [100, 200, 300, 400, 500, 600, 700, 800, 900, 1
graph_creation_times_average = [0] * input_sizes_complete.__len__()
num_trials = 25
for j in range(num_trials):
    graph_creation_times = []
    for i in input_sizes_complete:
        time_start = 0
        time_start = time.time()
        graph = CreateGraph(i, 100, 'COMPLETE', 'UNIFORM')
        graph.populate()
        time_end = time.time()
        graph_creation_times.append(time_end - time_start)

    for x in range(graph_creation_times.__len__()):
        graph_creation_times_average[x] += graph_creation_times[x]

for x in range(graph_creation_times_average.__len__()):
    graph_creation_times_average[x] /= num_trials

df = pd.DataFrame(columns = ['Input Size', 'Time'])
df['Input Size'] = input_sizes_complete
df['Time'] = graph_creation_times_average
display(df)

plt.plot(input_sizes_complete, graph_creation_times_average)
plt.title('Complete Graph Creation Timing')
plt.xlabel('Input Size as Number of Vertices')
plt.ylabel('Time (s)')
plt.show()
```

```
Complete Graph
```

	Input Size	Time
0	100	0.148051
1	200	0.026808
2	300	0.065841
3	400	0.121399
4	500	0.199677
5	600	0.295449
6	700	0.408320
7	800	0.539783
8	900	0.690637
9	1000	0.846911


Complete Graph Creation Timing
Time (s)
0.0
0.2
0.4
0.6
0.8
200
400
600
800
1000
Input Size as Number of Vertices

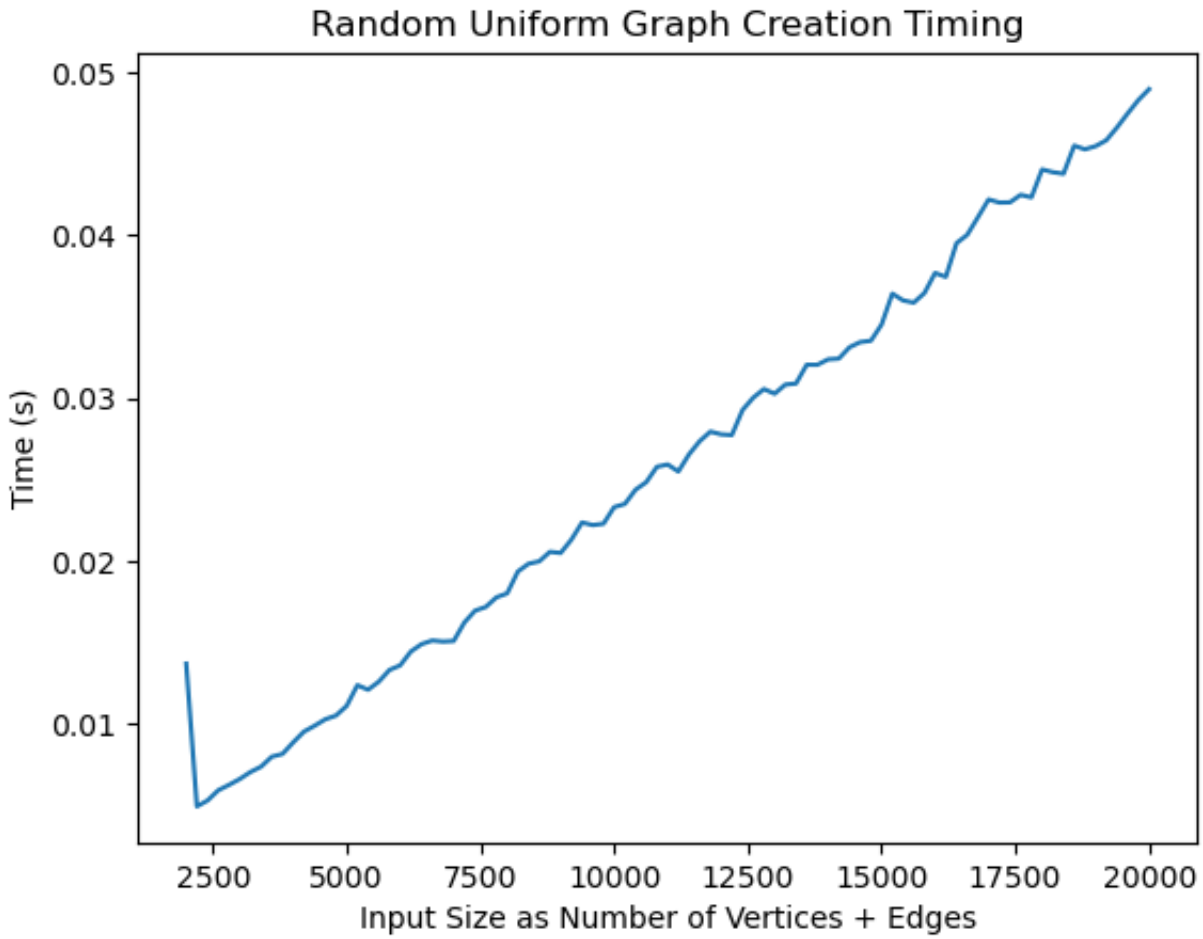
In [231]:

```
vertex_counts = [i for i in range(1000, 10001, 100)]
edges_counts = [i for i in range(1000, 10001, 100)]
# add vertex counts and edge counts to make input_sizes_random_uni
input_sizes_random_uni = []
for j in range(vertex_counts.__len__()):
    input_sizes_random_uni.append((vertex_counts[j] + edges_counts[j])

print("Random Uniform Graph")
graph_creation_times_average = [0] * input_sizes_random_uni.__len__()
num_trials = 25
for j in range(num_trials):
    graph_creation_times = []
    for i in range(input_sizes_random_uni.__len__()):
        time_start = 0
        time_start = time.time()
        graph = CreateGraph(vertex_counts[i], edges_counts[i], 'RANDOM
        graph.populate()
        time_end = time.time()
        graph_creation_times.append(time_end - time_start)

    for x in range(graph_creation_times.__len__()):
        graph_creation_times_average[x] += graph_creation_times[x]

for x in range(graph_creation_times_average.__len__()):
    graph_creation_times_average[x] /= num_trials

df = pd.DataFrame(columns = ['Input Size', 'Time'])
#put every 10th value in the input_sizes_random_uni list into the data
df['Input Size'] = input_sizes_random_uni[::10]
df['Time'] = graph_creation_times_average[::10]
display(df)

plt.plot(input_sizes_random_uni, graph_creation_times_average)
plt.title('Random Uniform Graph Creation Timing')
plt.xlabel('Input Size as Number of Vertices + Edges')
plt.ylabel('Time (s)')
plt.show()
```

Random Uniform Graph

	Input Size	Time
0	2000	0.013677
1	4000	0.008843
2	6000	0.013574
3	8000	0.017996
4	10000	0.023292

5	12000	0.027761
6	14000	0.032367
7	16000	0.037671
8	18000	0.044030
9	20000	0.048960



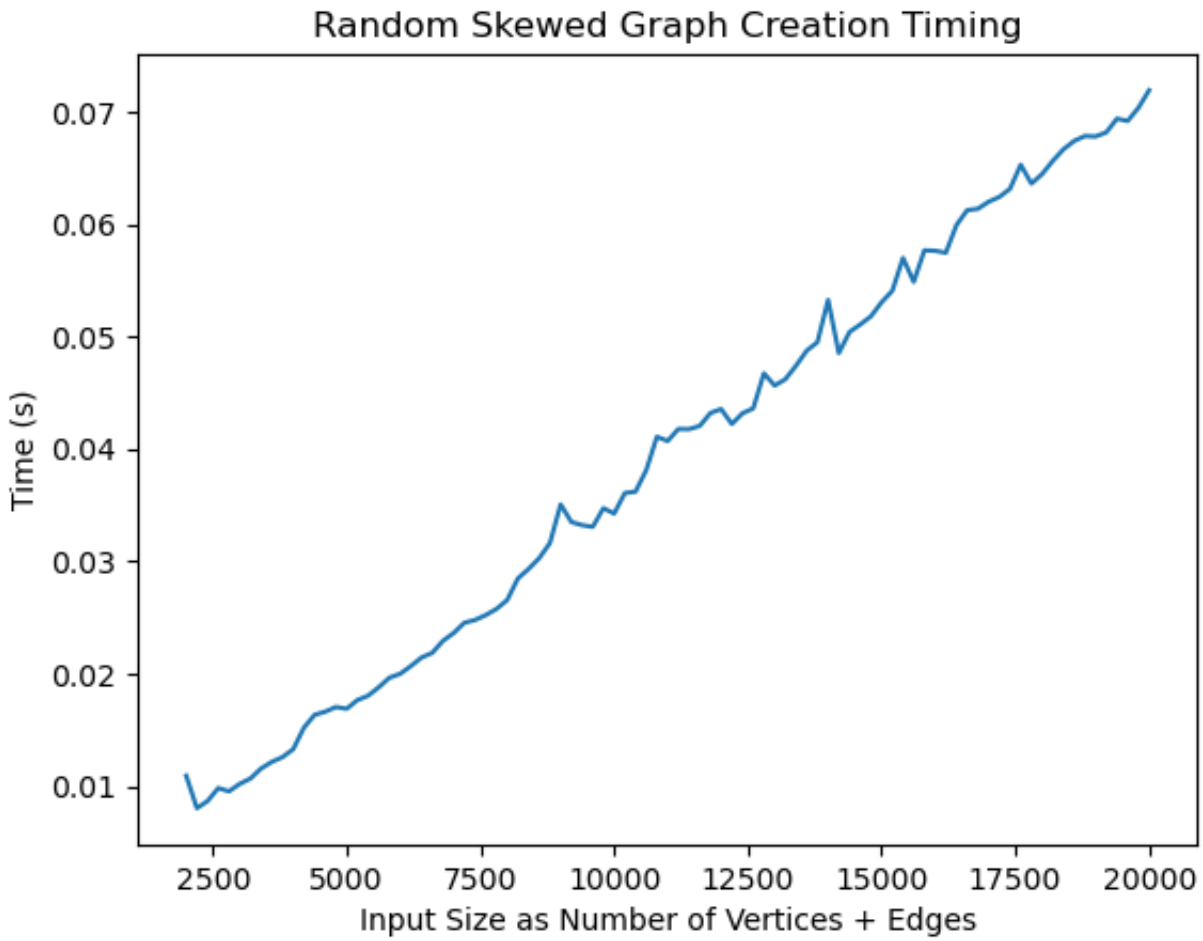
In [232]:

```
vertex_counts = [i for i in range(1000, 10001, 100)]
edges_counts = [i for i in range(1000, 10001, 100)]
# add vertex counts and edge counts to make input_sizes_random_uni
input_sizes_random_skewed = []
for j in range(vertex_counts.__len__()):
    input_sizes_random_skewed.append((vertex_counts[j] + edges_counts[

print("Random Skewed Graph")
graph_creation_times_average = [0] * input_sizes_random_skewed.__len__
num_trials = 25
for j in range(num_trials):
    graph_creation_times = []
    for i in range(input_sizes_random_skewed.__len__()):
        time_start = 0
        time_start = time.time()
        graph = CreateGraph(vertex_counts[i], edges_counts[i], 'RANDOM
        graph.populate()
        time_end = time.time()
        graph_creation_times.append(time_end - time_start)

    for x in range(graph_creation_times.__len__()):
        graph_creation_times_average[x] += graph_creation_times[x]

for x in range(graph_creation_times_average.__len__()):
    graph_creation_times_average[x] /= num_trials

df = pd.DataFrame(columns = ['Input Size', 'Time'])
#put every 10th value in the input_sizes_random_uni list into the data
df['Input Size'] = input_sizes_random_skewed[::10]
df['Time'] = graph_creation_times_average[::10]
display(df)

plt.plot(input_sizes_random_uni, graph_creation_times_average)
plt.title('Random Skewed Graph Creation Timing')
plt.xlabel('Input Size as Number of Vertices + Edges')
plt.ylabel('Time (s)')
plt.show()
```

```
Random Skewed Graph
```

	Input Size	Time
0	2000	0.010918
1	4000	0.013275
2	6000	0.019982
3	8000	0.026541
4	10000	0.034247
5	12000	0.043548

6	14000	0.053264
7	16000	0.057637
8	18000	0.064463
9	20000	0.071922



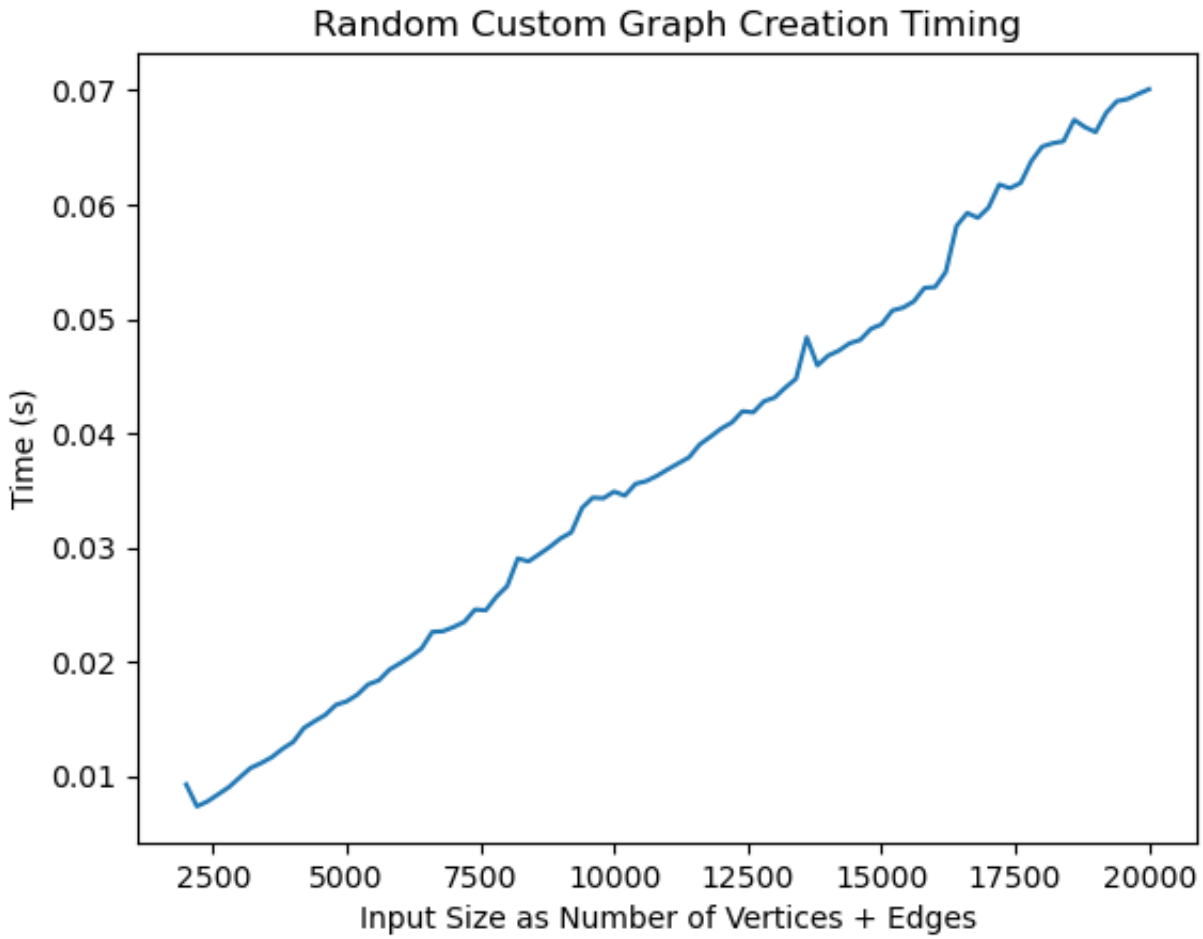
In [233]:

```
vertex_counts = [i for i in range(1000, 10001, 100)]
edges_counts = [i for i in range(1000, 10001, 100)]
# add vertex counts and edge counts to make input_sizes_random_uni
input_sizes_random_custom = []
for j in range(vertex_counts.__len__()):
    input_sizes_random_custom.append((vertex_counts[j] + edges_counts[

print("Random Custom Graph")
graph_creation_times_average = [0] * input_sizes_random_custom.__len__
num_trials = 25
for j in range(num_trials):
    graph_creation_times = []
    for i in range(input_sizes_random_skewed.__len__()):
        time_start = 0
        time_start = time.time()
        graph = CreateGraph(vertex_counts[i], edges_counts[i], 'RANDOM
        graph.populate()
        time_end = time.time()
        graph_creation_times.append(time_end - time_start)

    for x in range(graph_creation_times.__len__()):
        graph_creation_times_average[x] += graph_creation_times[x]

for x in range(graph_creation_times_average.__len__()):
    graph_creation_times_average[x] /= num_trials

df = pd.DataFrame(columns = ['Input Size', 'Time'])
#put every 10th value in the input_sizes_random_uni list into the data
df['Input Size'] = input_sizes_random_custom[::10]
df['Time'] = graph_creation_times_average[::10]
display(df)

plt.plot(input_sizes_random_uni, graph_creation_times_average)
plt.title('Random Custom Graph Creation Timing')
plt.xlabel('Input Size as Number of Vertices + Edges')
plt.ylabel('Time (s)')
plt.show()
```

```
Random Custom Graph
```

	Input Size	Time
0	2000	0.009251
1	4000	0.012961
2	6000	0.019853
3	8000	0.026607
4	10000	0.034881
5	12000	0.040389

6	14000	0.046779
7	16000	0.052777
8	18000	0.065068
9	20000	0.070101



Timing of Ordering Algorithms

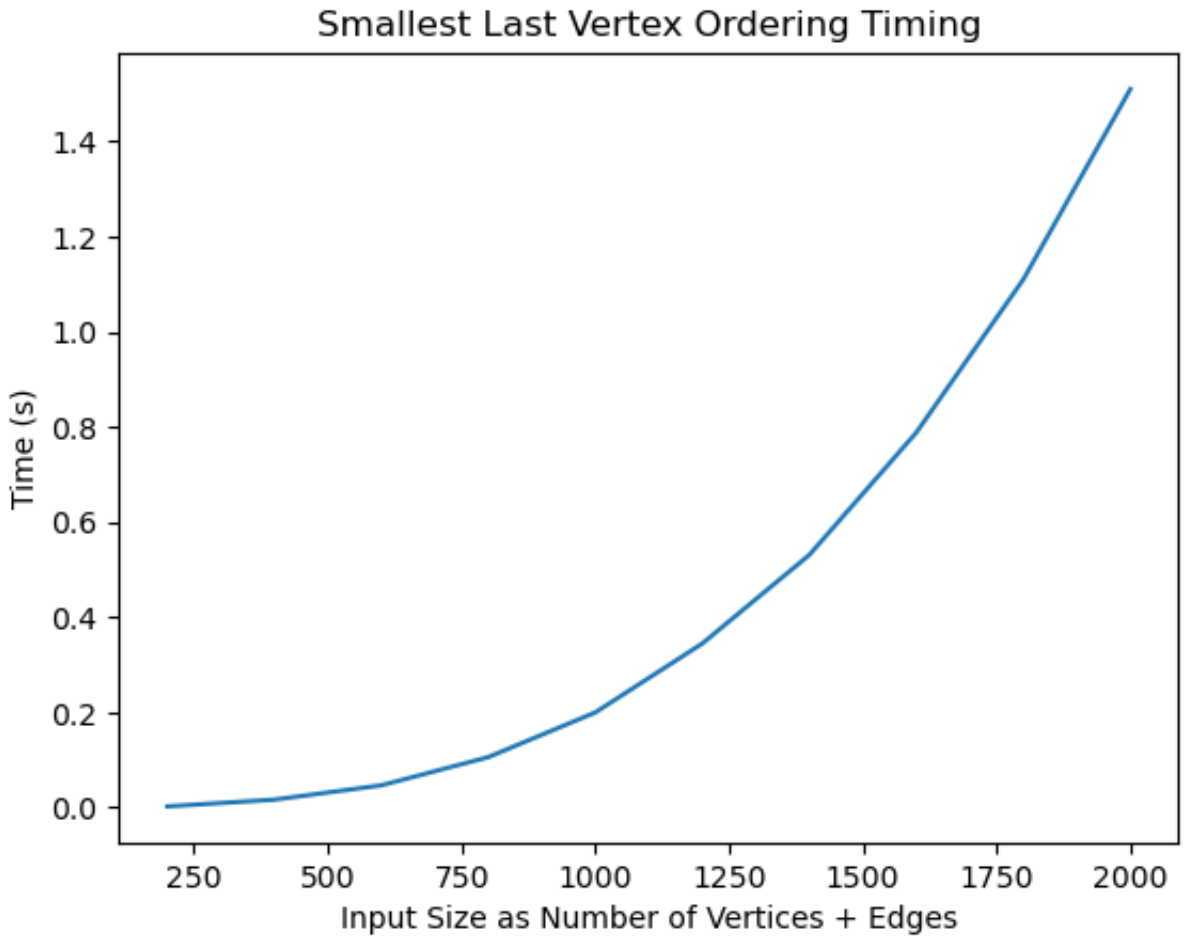
In [247]:

```
vertex_counts = [i for i in range(100, 1001, 100)]
edges_counts = [i for i in range(100, 1001, 100)]
# add vertex counts and edge counts to make input_sizes_random_uni
input_sizes_random_uni = []
for j in range(vertex_counts.__len__()):
    input_sizes_random_uni.append((vertex_counts[j] + edges_counts[j])

print("Smallest Last Vertex Ordering")
graph_creation_times_average = [0] * input_sizes_random_uni.__len__()
num_trials = 25
for j in range(num_trials):
    graph_creation_times = []
    for i in range(input_sizes_random_uni.__len__()):
        graph = CreateGraph(vertex_counts[i], edges_counts[i], 'RANDOM
        graph.populate()
        degrees = graph.getDegrees()


        time_start = 0
        time_start = time.time()
        ordering = graph.getSmallestLastVertexOrdering(degrees)
        time_end = time.time()

        coloring = graph.colorGraph(ordering)
        graph_creation_times.append(time_end - time_start)

    for x in range(graph_creation_times.__len__()):
        graph_creation_times_average[x] += graph_creation_times[x]

for x in range(graph_creation_times_average.__len__()):
    graph_creation_times_average[x] /= num_trials

df = pd.DataFrame(columns = ['Input Size', 'Time'])
#put every 10th value in the input_sizes_random_uni list into the data
df['Input Size'] = input_sizes_random_uni[::1]
df['Time'] = graph_creation_times_average[::1]
display(df)

plt.plot(input_sizes_random_uni, graph_creation_times_average)
plt.title('Smallest Last Vertex Ordering Timing')
plt.xlabel('Input Size as Number of Vertices + Edges')
plt.ylabel('Time (s)')
plt.show()
```

```
Smallest Last Vertex Ordering
```

	Input Size	Time
0	200	0.002266
1	400	0.016415

2	600	0.046508
3	800	0.105857
4	1000	0.199817
5	1200	0.344724
6	1400	0.530976
7	1600	0.788341
8	1800	1.110274
9	2000	1.510243



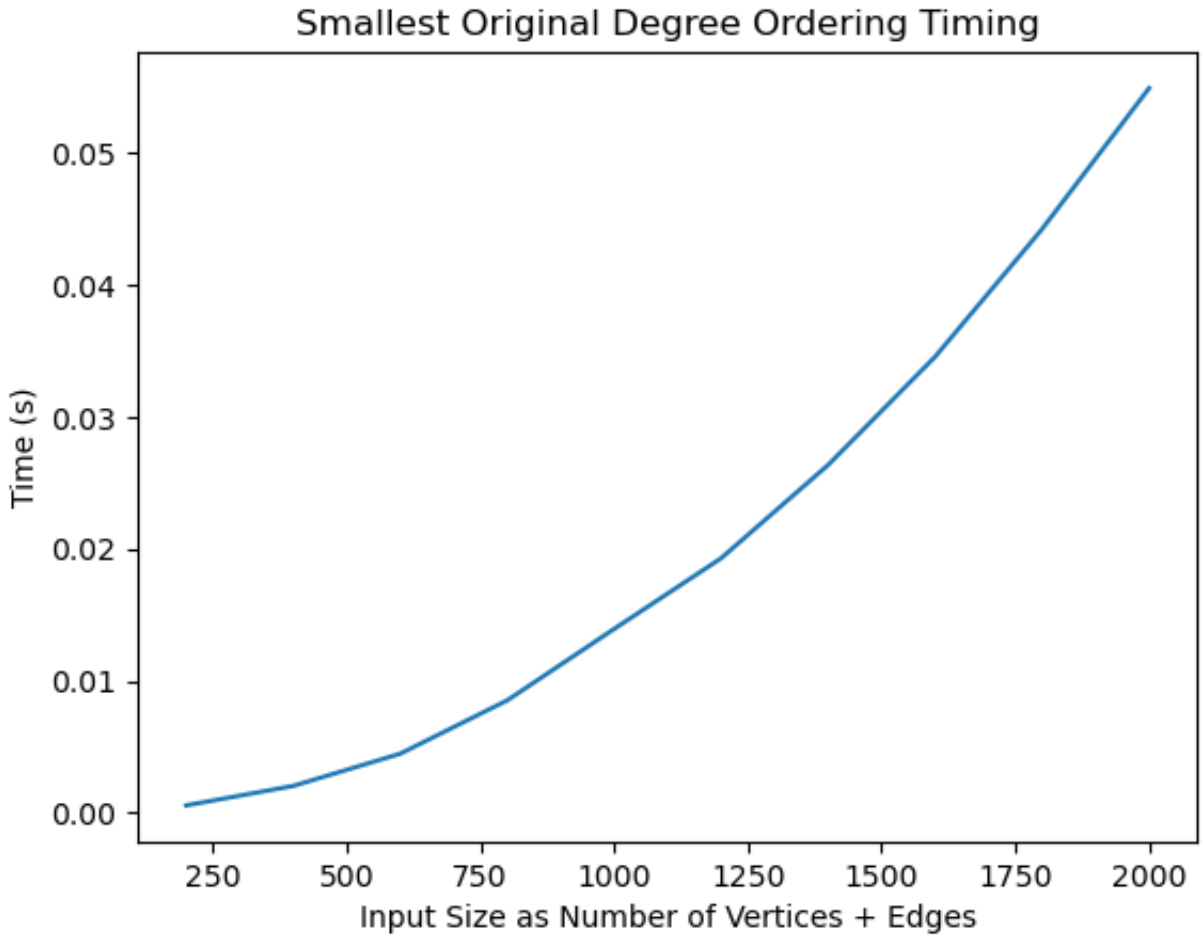
In [248]:

```
vertex_counts = [i for i in range(100, 1001, 100)]
edges_counts = [i for i in range(100, 1001, 100)]
# add vertex counts and edge counts to make input_sizes_random_uni
input_sizes_random_uni = []
for j in range(vertex_counts.__len__()):
    input_sizes_random_uni.append((vertex_counts[j] + edges_counts[j])

print("Smallest Original Degree Ordering")
graph_creation_times_average = [0] * input_sizes_random_uni.__len__()
num_trials = 25
for j in range(num_trials):
    graph_creation_times = []
    for i in range(input_sizes_random_uni.__len__()):
        graph = CreateGraph(vertex_counts[i], edges_counts[i], 'RANDOM
        graph.populate()
        degrees = graph.getDegrees()

        time_start = 0
        time_start = time.time()
        ordering = graph.getSmallestOriginalDegreeOrdering(degrees)
        time_end = time.time()

        coloring = graph.colorGraph(ordering)
        graph_creation_times.append(time_end - time_start)

    for x in range(graph_creation_times.__len__()):
        graph_creation_times_average[x] += graph_creation_times[x]

for x in range(graph_creation_times_average.__len__()):
    graph_creation_times_average[x] /= num_trials

df = pd.DataFrame(columns = ['Input Size', 'Time'])
#put every 10th value in the input_sizes_random_uni list into the data
df['Input Size'] = input_sizes_random_uni[::1]
df['Time'] = graph_creation_times_average[::1]
display(df)

plt.plot(input_sizes_random_uni, graph_creation_times_average)
plt.title('Smallest Original Degree Ordering Timing')
plt.xlabel('Input Size as Number of Vertices + Edges')
plt.ylabel('Time (s)')
plt.show()
```

```
Smallest Original Degree Ordering
```

	Input Size	Time
0	200	0.000575
1	400	0.002047
2	600	0.004486

2	600	0.004486
3	800	0.008525
4	1000	0.013940
5	1200	0.019295
6	1400	0.026358
7	1600	0.034552
8	1800	0.044226
9	2000	0.054896



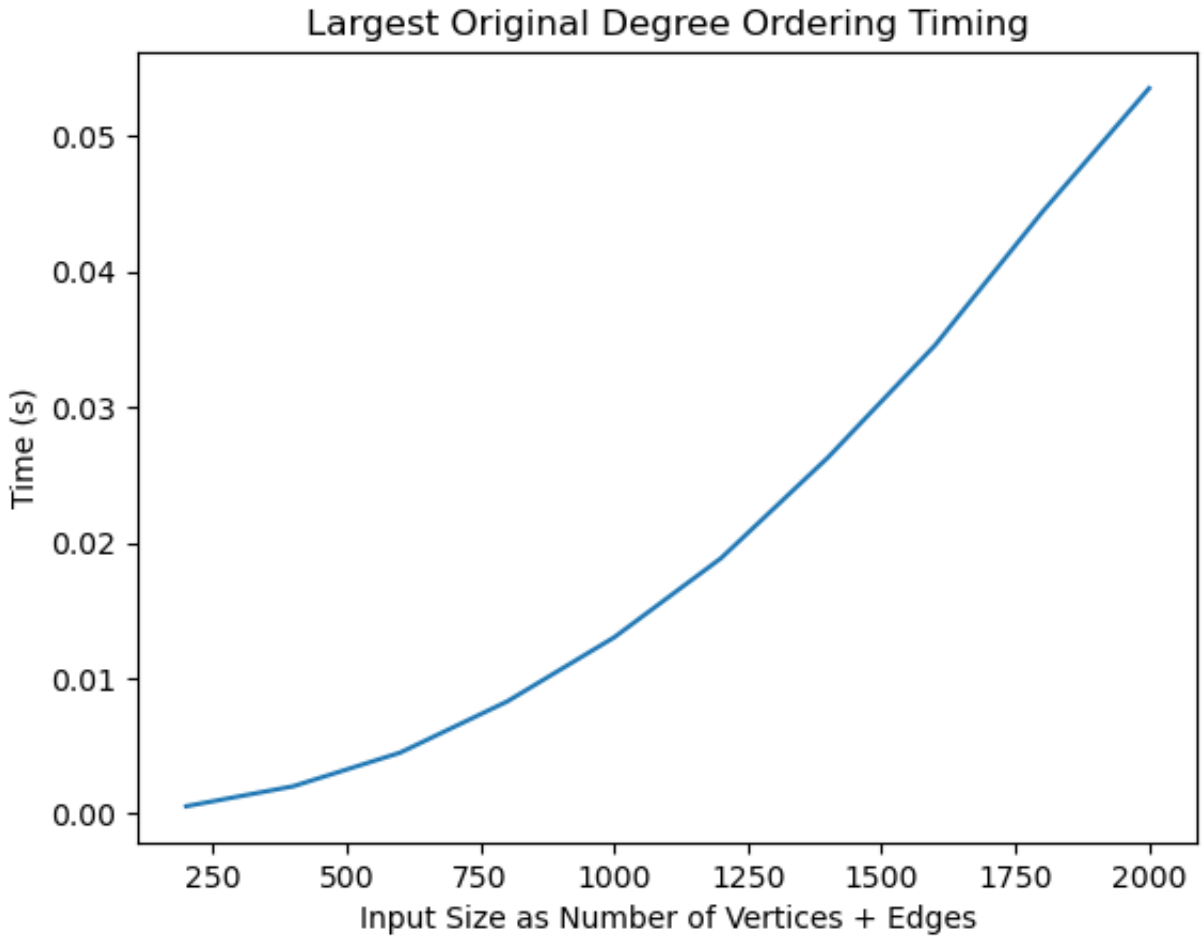
In [251]:

```
vertex_counts = [i for i in range(100, 1001, 100)]
edges_counts = [i for i in range(100, 1001, 100)]
# add vertex counts and edge counts to make input_sizes_random_uni
input_sizes_random_uni = []
for j in range(vertex_counts.__len__()):
    input_sizes_random_uni.append((vertex_counts[j] + edges_counts[j])

print("Largest Original Degree Ordering")
graph_creation_times_average = [0] * input_sizes_random_uni.__len__()
num_trials = 25
for j in range(num_trials):
    graph_creation_times = []
    for i in range(input_sizes_random_uni.__len__()):
        graph = CreateGraph(vertex_counts[i], edges_counts[i], 'RANDOM
        graph.populate()
        degrees = graph.getDegrees()

        time_start = 0
        time_start = time.time()
        ordering = graph.getLargestOriginalDegreeOrdering(degrees)
        time_end = time.time()

        coloring = graph.colorGraph(ordering)
        graph_creation_times.append(time_end - time_start)

    for x in range(graph_creation_times.__len__()):
        graph_creation_times_average[x] += graph_creation_times[x]

for x in range(graph_creation_times_average.__len__()):
    graph_creation_times_average[x] /= num_trials

df = pd.DataFrame(columns = ['Input Size', 'Time'])
#put every 10th value in the input_sizes_random_uni list into the data
df['Input Size'] = input_sizes_random_uni[::1]
df['Time'] = graph_creation_times_average[::1]
display(df)

plt.plot(input_sizes_random_uni, graph_creation_times_average)
plt.title('Largest Original Degree Ordering Timing')
plt.xlabel('Input Size as Number of Vertices + Edges')
plt.ylabel('Time (s)')
plt.show()
```

Largest Original Degree Ordering

	Input Size	Time
0	200	0.000561
1	400	0.002033
2	600	0.004514

2	600	0.004514
3	800	0.008289
4	1000	0.013019
5	1200	0.018864
6	1400	0.026301
7	1600	0.034576
8	1800	0.044380
9	2000	0.053525



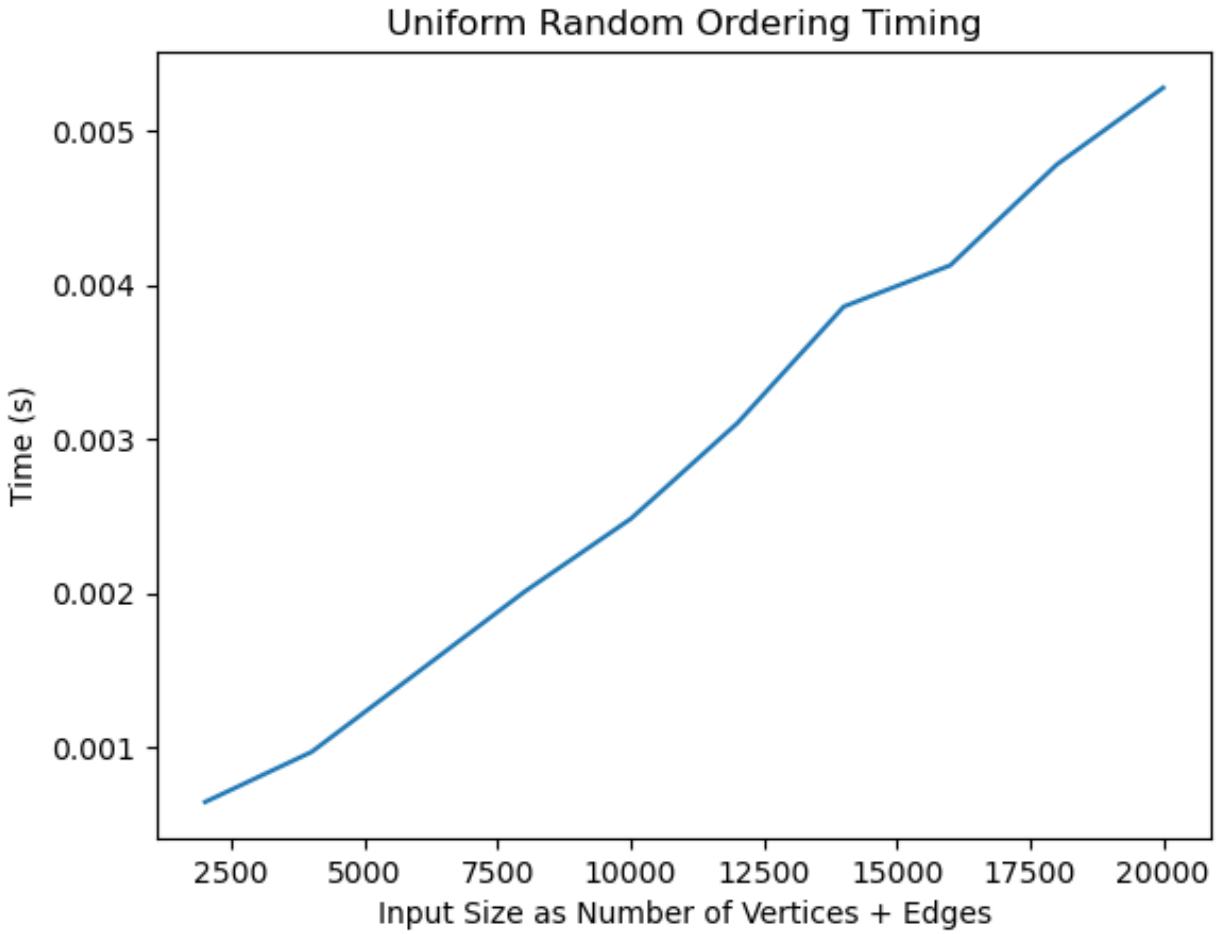
In [254]:

```
vertex_counts = [i for i in range(1000, 10001, 1000)]
edges_counts = [i for i in range(1000, 10001, 1000)]
# add vertex counts and edge counts to make input_sizes_random_uni
input_sizes_random_uni = []
for j in range(vertex_counts.__len__()):
    input_sizes_random_uni.append((vertex_counts[j] + edges_counts[j])

print("Uniform Random Ordering")
graph_creation_times_average = [0] * input_sizes_random_uni.__len__()
num_trials = 25
for j in range(num_trials):
    graph_creation_times = []
    for i in range(input_sizes_random_uni.__len__()):
        graph = CreateGraph(vertex_counts[i], edges_counts[i], 'RANDOM
        graph.populate()
        degrees = graph.getDegrees()

        time_start = 0
        time_start = time.time()
        ordering = graph.getUniformRandomOrdering()
        time_end = time.time()

        coloring = graph.colorGraph(ordering)
        graph_creation_times.append(time_end - time_start)

    for x in range(graph_creation_times.__len__()):
        graph_creation_times_average[x] += graph_creation_times[x]

for x in range(graph_creation_times_average.__len__()):
    graph_creation_times_average[x] /= num_trials

df = pd.DataFrame(columns = ['Input Size', 'Time'])
#put every 10th value in the input_sizes_random_uni list into the data
df['Input Size'] = input_sizes_random_uni[::1]
df['Time'] = graph_creation_times_average[::1]
display(df)

plt.plot(input_sizes_random_uni, graph_creation_times_average)
plt.title('Uniform Random Ordering Timing')
plt.xlabel('Input Size as Number of Vertices + Edges')
plt.ylabel('Time (s)')
plt.show()
```

Uniform Random Ordering

	Input Size	Time
0	2000	0.000641
1	4000	0.000966
2	6000	0.001486

2	6000	0.001486
3	8000	0.002007
4	10000	0.002482
5	12000	0.003103
6	14000	0.003860
7	16000	0.004128
8	18000	0.004783
9	20000	0.005282



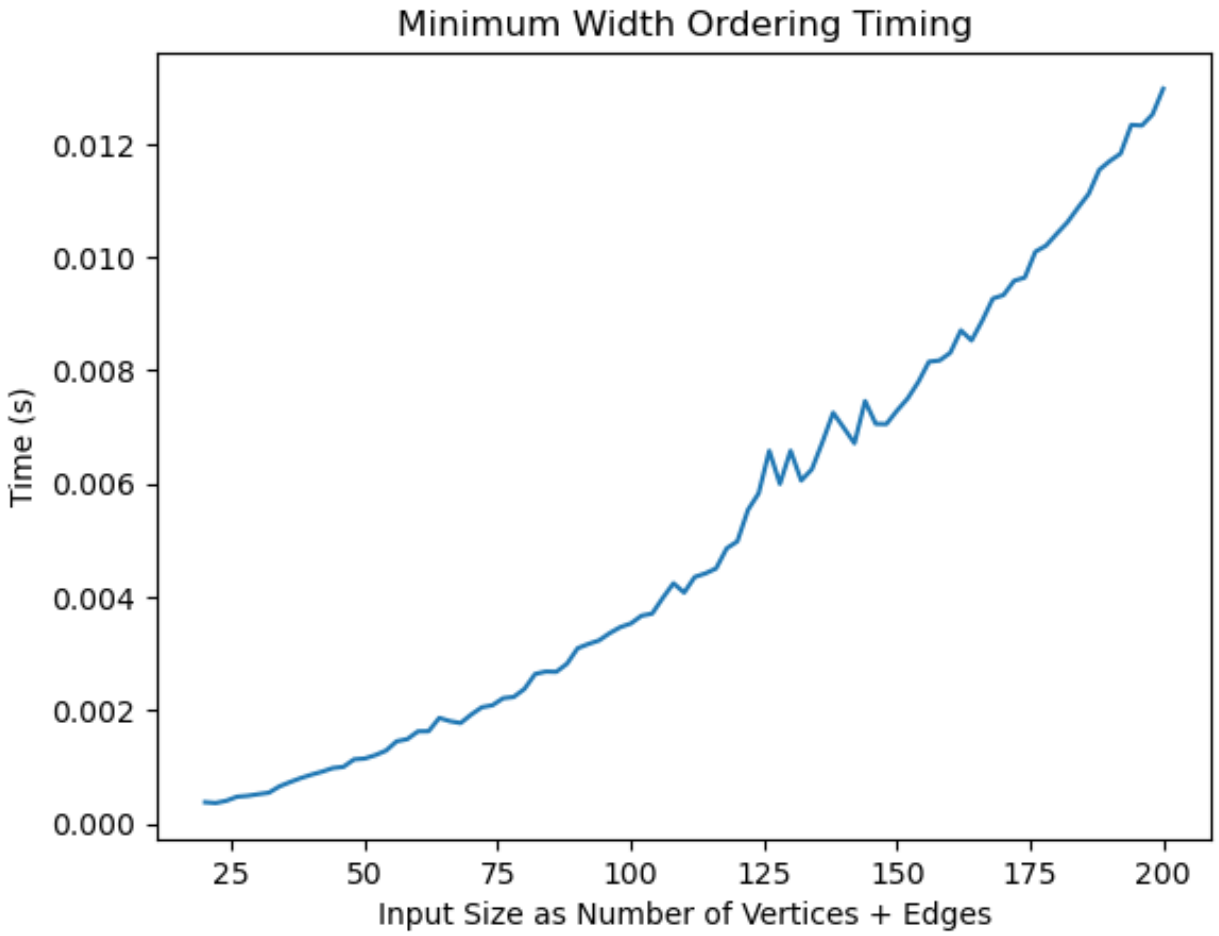
In [258]:

```
vertex_counts = [i for i in range(10, 101, 1)]
edges_counts = [i for i in range(10, 101, 1)]
# add vertex counts and edge counts to make input_sizes_random_uni
input_sizes_random_uni = []
for j in range(vertex_counts.__len__()):
    input_sizes_random_uni.append((vertex_counts[j] + edges_counts[j])

print("Minimum Width Ordering")
graph_creation_times_average = [0] * input_sizes_random_uni.__len__()
num_trials = 25
for j in range(num_trials):
    graph_creation_times = []
    for i in range(input_sizes_random_uni.__len__()):
        graph = CreateGraph(vertex_counts[i], edges_counts[i], 'RANDOM
        graph.populate()
        degrees = graph.getDegrees()

        time_start = 0
        time_start = time.time()
        ordering = graph.getMinimumWidthOrdering(degrees)
        time_end = time.time()

        coloring = graph.colorGraph(ordering)
        graph_creation_times.append(time_end - time_start)

    for x in range(graph_creation_times.__len__()):
        graph_creation_times_average[x] += graph_creation_times[x]

for x in range(graph_creation_times_average.__len__()):
    graph_creation_times_average[x] /= num_trials

df = pd.DataFrame(columns = ['Input Size', 'Time'])
#put every 10th value in the input_sizes_random_uni list into the data
df['Input Size'] = input_sizes_random_uni[::10]
df['Time'] = graph_creation_times_average[::10]
display(df)

plt.plot(input_sizes_random_uni, graph_creation_times_average)
plt.title('Minimum Width Ordering Timing')
plt.xlabel('Input Size as Number of Vertices + Edges')
plt.ylabel('Time (s)')
plt.show()
```

```
Minimum Width Ordering
```

	Input Size	Time
0	20	0.000380
1	40	0.000867
2	60	0.001630

2	60	0.001630
3	80	0.002379
4	100	0.003535
5	120	0.004984
6	140	0.006987
7	160	0.008311
8	180	0.010412
9	200	0.012972



In [ ]: