Project 2
机场模拟

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1 题目要求

书本在P96-P109中提供了一个机场模拟器的实现代码。首先我们分别有两个队列，一个控制起飞一个控制降落，而我们拥有一个供飞机起飞降落的跑道（每次只能进行起飞或者降落中的一个操作）。飞机的起降数目由随机函数生成，每个时刻进入起飞序列或降落序列的飞机数目都满足泊松分布。程序输入为起降队列的长度限制，机场运作的总时间、起飞飞机的比率、降落飞机的比率，程序的输出为机场各跑道起降情况、飞机入队情况以及模拟结束后各种数据的汇总。

这次的项目将在上述机场模拟器的基础上，分别实现以下六个要求：

- 整合书中的程序，并做几组实验，调整起降飞机的数目，找出尽可能大的合适参数使得飞机尽可能不被机场拒绝起降，并探究队列大小的改变会对结果造成怎样的影响。
- 把机场跑道数改为两条，一条只用于降落另一条只用于起飞，比较跑道数倍增后机场的客机吞吐量是否多于原来的两倍。
- 机场跑道数仍为两条，一条主要用于降落另一条主要用于起飞。当其中一条跑道闲置的时候，可为另一条跑道分流；当着陆队列满后，两条跑道都将被用于着陆，直到着陆序列为空。
- 跑道数目增加到三条，第三条跑道主要用于飞机降落，当着陆队列为空时可用于起飞。
- 回到单跑道状态，为飞机添加一个燃油量属性，燃料以剩余时间作为单位。若飞机燃料不足，则其可被允许优先降落。探究在此情况下，机场的最大吞吐量。
- 去除随机函数，通过用户输入指定每一个时间单位的起降飞机数目，以便调试。

2 数据结构与算法

这题考察的数据结构是**队列**，是一个**先进先出**的结构。本题涉及到两个队列—起飞队列和着陆队列，我们用`push()`和`pop()`函数来控制入队和出队。由于六个小题涉及到的类相同，仅仅是成员函数的不同，因此我们将所有代码都集成到了一个程序中，通过命令行直接传入参数（问题的编号）来控制程序功能，这是我们程序的一个亮点所在。

题一较为简单，先将课本中的代码部分（包括Appendix中的随机数）进行代码整合，然后通过输入不同的arrival_rate和departure_rate组合进行测试。实验结果在章节3给出。

题二则类似题一，只是增加了一条跑道。由于跑道的职能类似，实现较简单，唯一不同就是要在输出部分确定飞机从哪个跑道起飞或降落。在这里我们使用一个`vector`容器来储存不同的runway，而对于某一条runway，其可以四种状态中的某一种，包括：主要用于

着陆(mainly_landing)、主要用于起飞(mainly_takeoff)、仅用于着陆(only_landing)、仅用于起飞(only_takeoff)。初始两条跑道状态为only_landing和only_takeoff，然后分别掌管各自队列的任务即可。注意，这里我们发现了各个问题之间的共同之处，并将问题的结构进行抽象，最终抽象出四种跑道的状态，这也是我们程序的一大亮点。

题三在题二的基础上稍有改动，两条跑道的初始状态改为mainly_landing和mainly_takeoff，当降落或起飞的某一条队列为空时，对应跑道即可进行另外一种操作。如降落队列为空，mainly_landing跑道便可执行起飞操作。此外，本题还增加了剩余队列清理(backlog clear)功能，当降落队列满时两个跑道同时用于清空降落队列，直到降落队列为空，输出"Landing backlog cleared"提示。注意本题我们用了一个类似有限状态机的写法，在`Runway`类内构造了一个change_runway_status成员函数，用于更改跑道的不同状态。

题四在题二的基础上增加了一条状态为mainly_landing的跑道，实现方法与题三基本相同，在此不再赘述。

题五要求我们对飞机添加油量这一参数，并设定一定的算法使得飞机尽可能不要因为燃油不足而坠毁。对于这个问题，我们优先对燃油量较低的飞机进行降落。如果燃油不足以使得飞机飞到机场，则飞机进入紧急状态，并暂停机场中一切起飞和降落活动，对紧急状态飞机进行优先降落。为增强整个算法的正确性和健壮性，我们对航油不足的情况进行相应的分析，并查阅了《民用航空空中交通管理规则 (CCAR-93-R5)》中的相关规定：

- 第四百八十四条　　最低油量表示航空器燃油油量已达到不能再耽搁的状态。最低油量非指紧急状况，仅表示如果再出现不适当耽搁很可能发生紧急状况。当航空器报告最低油量时，管制员应当：
  - 尽可能保障航空器按照计划航迹飞行，减少不必要的飞行延迟和等待，防止航空器进入"紧急油量"状态；
  - 及时将该航空器"最低油量"状况通报给将要移交的下一管制单位。

因此，我们可以提前引导油量不足的飞机先行降落以减少伤亡。鉴于本题是一个单跑道情形，我们可以检测在每一架飞机的油量，如果遇到即将遇险的飞机，可以安排其与前机在同一个时间段内降落。具体到程序，我们给每一架飞机增加了一个fuel成员，并添加一个reduce_fuel函数，当某架飞机的燃油量小于一个阈值时，机场进入紧急状态。

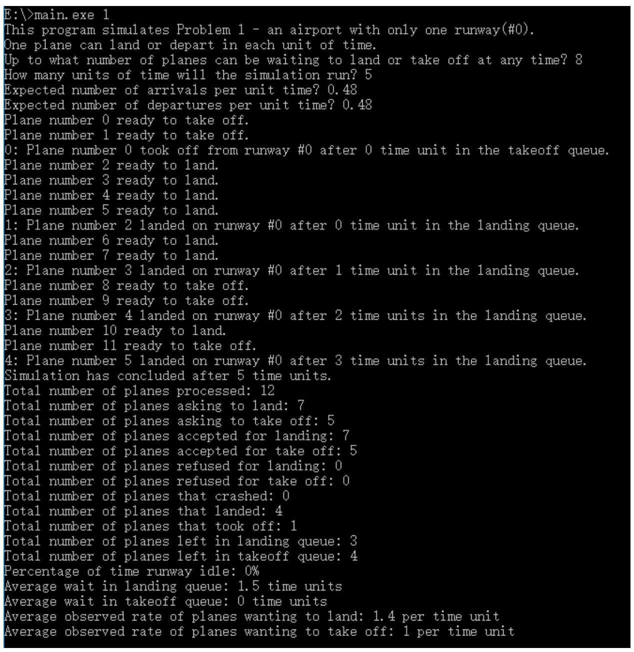
题六需要将随机函数更改为手工输入。故我们在程序中引入布尔参数`manual_mode`(默认为假)，通过命令行读入，若其为真时，随机函数变更为手动输入。注意我们这种实现方式是同时针对前面五个问题都可以使用的，大大增强了代码的可用性。

最后值得一提的是，我们的程序对原来课本的程序进行进一步的抽象、优化、代码整

合，使得代码结构更加清晰易懂。如将main函数中关于moving_plane的部分整合入activity中，保证类关系的一致性，同时去除无意义的参数传递。

3 测试数据、结果及分析

我们对每一个问题都做了多组实验，这里对于每个问题都仅展示两组实验结果，一组飞机量较为小，每个单位时间的飞机量小于1，另一组则飞机量较大，每个单位时间的飞机量大于1。通过这些实验，观察结果，得出结论。

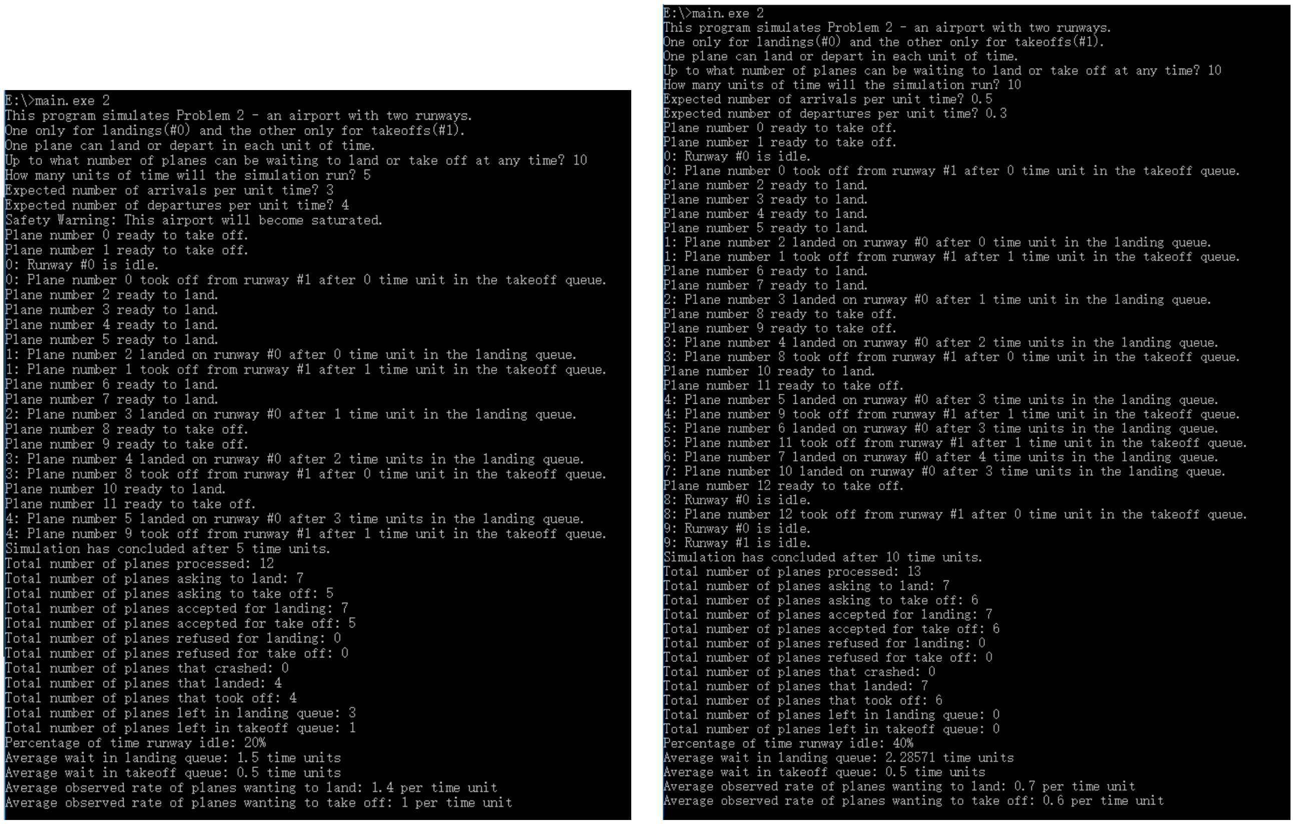


```
E:\>main.exe 1
This program simulates Problem 1 - an airport with only one runway(#0).
One plane can land or depart in each unit of time.
Up to what number of planes can be waiting to land or take off at any time? 8
How many units of time will the simulation run? 5
Expected number of arrivals per unit time? 0.48
Expected number of departures per unit time? 0.48
Plane number 0 ready to take off.
Plane number 1 ready to take off.
0: Plane number 0 took off from runway #0 after 0 time unit in the takeoff queue.
Plane number 2 ready to land.
Plane number 3 ready to land.
Plane number 4 ready to land.
Plane number 5 ready to land.
1: Plane number 2 landed on runway #0 after 0 time unit in the landing queue.
Plane number 6 ready to land.
Plane number 7 ready to land.
2: Plane number 3 landed on runway #0 after 1 time unit in the landing queue.
Plane number 8 ready to take off.
Plane number 9 ready to take off.
3: Plane number 4 landed on runway #0 after 2 time units in the landing queue.
Plane number 10 ready to land.
Plane number 11 ready to take off.
4: Plane number 5 landed on runway #0 after 3 time units in the landing queue.
Simulation has concluded after 5 time units.
Total number of planes processed: 12
Total number of planes asking to land: 7
Total number of planes asking to take off: 5
Total number of planes accepted for landing: 7
Total number of planes accepted for take off: 5
Total number of planes refused for landing: 0
Total number of planes refused for take off: 0
Total number of planes that crashed: 0
Total number of planes that landed: 4
Total number of planes that took off: 1
Total number of planes left in landing queue: 3
Total number of planes left in takeoff queue: 4
Percentage of time runway idle: 0%
Average wait in landing queue: 1.5 time units
Average wait in takeoff queue: 0 time units
Average observed rate of planes wanting to land: 1.4 per time unit
Average observed rate of planes wanting to take off: 1 per time unit
```

```
E:\>main.exe 1
This program simulates Problem 1 - an airport with only one runway(#0).
One plane can land or depart in each unit of time.
Up to what number of planes can be waiting to land or take off at any time? 10
How many units of time will the simulation run? 5
Expected number of arrivals per unit time? 10
Expected number of departures per unit time? 5
Safety Warning: This airport will become saturated.
Plane number 0 ready to land.
Plane number 1 ready to land.
Plane number 2 ready to land.
Plane number 3 ready to take off.
Plane number 4 ready to take off.
Plane number 5 ready to take off.
Plane number 6 ready to take off.
0: Plane number 0 landed on runway #0 after 0 time unit in the landing queue.
Plane number 7 ready to take off.
Plane number 8 ready to take off.
1: Plane number 1 landed on runway #0 after 1 time unit in the landing queue.
2: Plane number 2 landed on runway #0 after 2 time units in the landing queue.
Plane number 9 ready to land.
Plane number 10 ready to land.
Plane number 11 ready to take off.
3: Plane number 9 landed on runway #0 after 0 time unit in the landing queue.
Plane number 12 ready to land.
4: Plane number 10 landed on runway #0 after 1 time unit in the landing queue.
Simulation has concluded after 5 time units.
Total number of planes processed: 13
Total number of planes asking to land: 6
Total number of planes asking to take off: 7
Total number of planes accepted for landing: 6
Total number of planes accepted for take off: 7
Total number of planes refused for landing: 0
Total number of planes refused for take off: 0
Total number of planes that crashed: 0
Total number of planes that landed: 5
Total number of planes that took off: 0
Total number of planes left in landing queue: 1
Total number of planes left in takeoff queue: 7
Percentage of time runway idle: 0%
Average wait in landing queue: 0.8 time units
Average wait in takeoff queue: nan time units
Average observed rate of planes wanting to land: 1.2 per time unit
Average observed rate of planes wanting to take off: 1.4 per time unit
```

图 1: 问题一实验结果

由图1可知：假设队列大小不变，模拟时间一定，当预期起飞和降落的数量之和最大且为队列大小的两倍时，飞机不太可能会被拒绝起飞和降落。如果其和超过两倍，被拒绝起飞或降落的可能性很大；因此两个数量的最优期望值是队列最大的情况，此时的机场运作效率最高。而通过改变输入的queue limit，我们得出的结论是：如果队列的最大值增大，而其它值不变，接受飞机起飞和降落的数量不变；如果队列最大值减少，其它值不变，接收的数量也会减少。

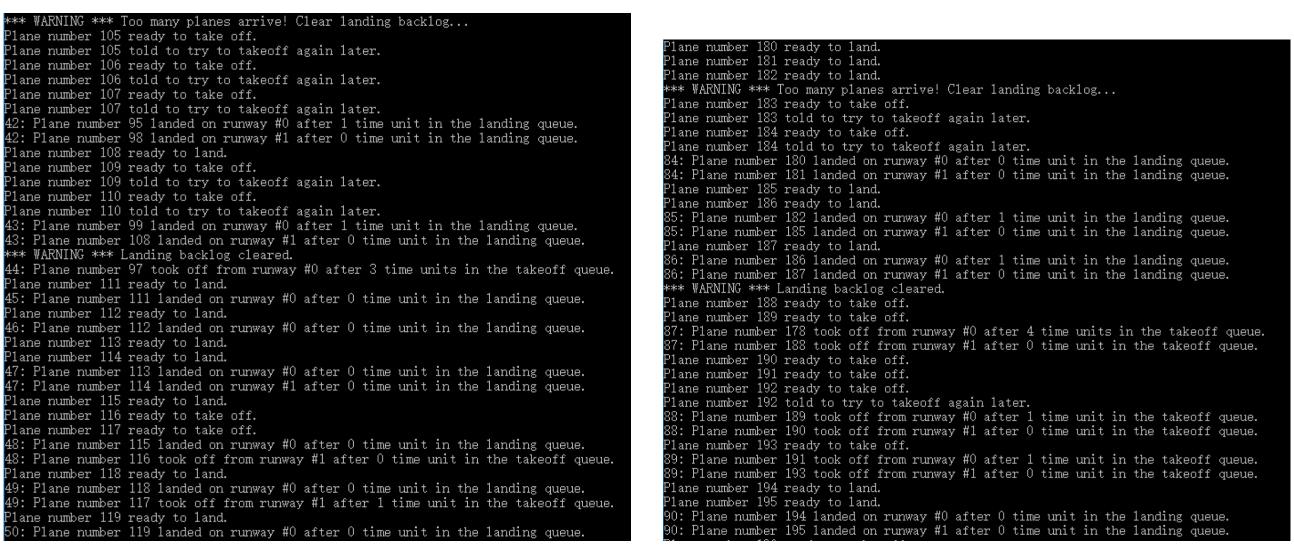


```
E:\>main.exe 2
This program simulates Problem 2 - an airport with two runways.
One only for landings(#0) and the other only for takeoffs(#1).
One plane can land or depart in each unit of time.
Up to what number of planes can be waiting to land or take off at any time? 10
How many units of time will the simulation run? 5
Expected number of arrivals per unit time? 3
Expected number of departures per unit time? 4
Safety Warning: This airport will become saturated.
Plane number 0 ready to take off.
Plane number 1 ready to take off.
0: Runway #0 is idle.
0: Plane number 0 took off from runway #1 after 0 time unit in the takeoff queue.
Plane number 2 ready to land.
Plane number 3 ready to land.
Plane number 4 ready to land.
Plane number 5 ready to land.
1: Plane number 2 landed on runway #0 after 0 time unit in the landing queue.
1: Plane number 1 took off from runway #1 after 1 time unit in the takeoff queue.
Plane number 6 ready to land.
Plane number 7 ready to land.
2: Plane number 3 landed on runway #0 after 1 time unit in the landing queue.
Plane number 8 ready to take off.
Plane number 9 ready to take off.
3: Plane number 4 landed on runway #0 after 2 time units in the landing queue.
3: Plane number 8 took off from runway #1 after 0 time unit in the takeoff queue.
Plane number 10 ready to land.
Plane number 11 ready to take off.
4: Plane number 5 landed on runway #0 after 3 time units in the landing queue.
4: Plane number 9 took off from runway #1 after 1 time unit in the takeoff queue.
Simulation has concluded after 5 time units.
Total number of planes processed: 12
Total number of planes asking to land: 7
Total number of planes asking to take off: 5
Total number of planes accepted for landing: 7
Total number of planes accepted for take off: 5
Total number of planes refused for landing: 0
Total number of planes refused for take off: 0
Total number of planes that crashed: 0
Total number of planes that landed: 4
Total number of planes that took off: 4
Total number of planes left in landing queue: 3
Total number of planes left in takeoff queue: 1
Percentage of time runway idle: 20%
Average wait in landing queue: 1.5 time units
Average wait in takeoff queue: 0.5 time units
Average observed rate of planes wanting to land: 1.4 per time unit
Average observed rate of planes wanting to take off: 1 per time unit
```

```
E:\>main.exe 2
This program simulates Problem 2 - an airport with two runways.
One only for landings(#0) and the other only for takeoffs(#1).
One plane can land or depart in each unit of time.
Up to what number of planes can be waiting to land or take off at any time? 10
How many units of time will the simulation run? 10
Expected number of arrivals per unit time? 0.5
Expected number of departures per unit time? 0.3
Plane number 0 ready to take off.
Plane number 1 ready to take off.
0: Runway #0 is idle.
0: Plane number 0 took off from runway #1 after 0 time unit in the takeoff queue.
Plane number 2 ready to land.
Plane number 3 ready to land.
Plane number 4 ready to land.
Plane number 5 ready to land.
1: Plane number 2 landed on runway #0 after 0 time unit in the landing queue.
1: Plane number 1 took off from runway #1 after 1 time unit in the takeoff queue.
Plane number 6 ready to land.
Plane number 7 ready to land.
2: Plane number 3 landed on runway #0 after 1 time unit in the landing queue.
Plane number 8 ready to take off.
Plane number 9 ready to take off.
3: Plane number 4 landed on runway #0 after 2 time units in the landing queue.
3: Plane number 8 took off from runway #1 after 0 time unit in the takeoff queue.
Plane number 10 ready to land.
Plane number 11 ready to take off.
4: Plane number 5 landed on runway #0 after 3 time units in the landing queue.
4: Plane number 9 took off from runway #1 after 1 time unit in the takeoff queue.
5: Plane number 6 landed on runway #0 after 3 time units in the landing queue.
5: Plane number 11 took off from runway #1 after 1 time unit in the takeoff queue.
6: Plane number 7 landed on runway #0 after 4 time units in the landing queue.
7: Plane number 10 landed on runway #0 after 3 time units in the landing queue.
Plane number 12 ready to take off.
8: Runway #0 is idle.
8: Plane number 12 took off from runway #1 after 0 time unit in the takeoff queue.
9: Runway #0 is idle.
9: Runway #1 is idle.
Simulation has concluded after 10 time units.
Total number of planes processed: 13
Total number of planes asking to land: 7
Total number of planes asking to take off: 6
Total number of planes accepted for landing: 7
Total number of planes accepted for take off: 6
Total number of planes refused for landing: 0
Total number of planes refused for take off: 0
Total number of planes that crashed: 0
Total number of planes that landed: 7
Total number of planes that took off: 6
Total number of planes left in landing queue: 0
Total number of planes left in takeoff queue: 0
Percentage of time runway idle: 40%
Average wait in landing queue: 2.28571 time units
Average wait in takeoff queue: 0.5 time units
Average observed rate of planes wanting to land: 0.7 per time unit
Average observed rate of planes wanting to take off: 0.6 per time unit
```

图 2: 问题二实验结果

由图2可知：当飞机量较少，即机场远未及饱和状态时，添加跑道对最终飞机接收数目的影响并不大；而当飞机量过大，机场已经达到饱和状态时，添加一条跑道可以近乎实现成倍飞机接收量的增长。



```
*** WARNING *** Too many planes arrive! Clear landing backlog...
Plane number 105 ready to take off.
Plane number 105 told to try to takeoff again later.
Plane number 106 ready to take off.
Plane number 106 told to try to takeoff again later.
Plane number 107 ready to take off.
Plane number 107 told to try to takeoff again later.
42: Plane number 95 landed on runway #0 after 1 time unit in the landing queue.
42: Plane number 98 landed on runway #1 after 0 time unit in the landing queue.
Plane number 108 ready to land.
Plane number 109 ready to take off.
Plane number 109 told to try to takeoff again later.
Plane number 110 ready to take off.
Plane number 110 told to try to takeoff again later.
43: Plane number 99 landed on runway #0 after 1 time unit in the landing queue.
43: Plane number 108 landed on runway #1 after 0 time unit in the landing queue.
*** WARNING *** Landing backlog cleared.
44: Plane number 97 took off from runway #0 after 3 time units in the takeoff queue.
Plane number 111 ready to land.
45: Plane number 111 landed on runway #0 after 0 time unit in the landing queue.
Plane number 112 ready to land.
46: Plane number 112 landed on runway #0 after 0 time unit in the landing queue.
Plane number 113 ready to land.
Plane number 114 ready to land.
47: Plane number 113 landed on runway #0 after 0 time unit in the landing queue.
47: Plane number 114 landed on runway #1 after 0 time unit in the landing queue.
Plane number 115 ready to land.
Plane number 116 ready to take off.
Plane number 117 ready to take off.
48: Plane number 115 landed on runway #0 after 0 time unit in the landing queue.
48: Plane number 116 took off from runway #1 after 0 time unit in the takeoff queue.
Plane number 118 ready to land.
49: Plane number 118 landed on runway #0 after 0 time unit in the landing queue.
49: Plane number 117 took off from runway #1 after 1 time unit in the takeoff queue.
Plane number 119 ready to land.
50: Plane number 119 landed on runway #0 after 0 time unit in the landing queue.
```

```
Plane number 180 ready to land.
Plane number 181 ready to land.
Plane number 182 ready to land.
*** WARNING *** Too many planes arrive! Clear landing backlog...
Plane number 183 ready to take off.
Plane number 183 told to try to takeoff again later.
Plane number 184 ready to take off.
Plane number 184 told to try to takeoff again later.
84: Plane number 180 landed on runway #0 after 0 time unit in the landing queue.
84: Plane number 181 landed on runway #1 after 0 time unit in the landing queue.
Plane number 185 ready to land.
Plane number 186 ready to land.
85: Plane number 182 landed on runway #0 after 1 time unit in the landing queue.
85: Plane number 185 landed on runway #1 after 0 time unit in the landing queue.
Plane number 187 ready to land.
86: Plane number 186 landed on runway #0 after 1 time unit in the landing queue.
86: Plane number 187 landed on runway #1 after 0 time unit in the landing queue.
*** WARNING *** Landing backlog cleared.
Plane number 188 ready to take off.
Plane number 189 ready to take off.
87: Plane number 178 took off from runway #0 after 4 time units in the takeoff queue.
87: Plane number 188 took off from runway #1 after 0 time unit in the takeoff queue.
Plane number 190 ready to take off.
Plane number 191 ready to take off.
Plane number 192 ready to take off.
Plane number 192 told to try to takeoff again later.
88: Plane number 189 took off from runway #0 after 1 time unit in the takeoff queue.
88: Plane number 190 took off from runway #1 after 0 time unit in the takeoff queue.
Plane number 193 ready to take off.
89: Plane number 191 took off from runway #0 after 1 time unit in the takeoff queue.
89: Plane number 193 took off from runway #1 after 0 time unit in the takeoff queue.
Plane number 194 ready to land.
Plane number 195 ready to land.
90: Plane number 194 landed on runway #0 after 0 time unit in the landing queue.
90: Plane number 195 landed on runway #1 after 0 time unit in the landing queue.
```

图 3: 问题三实验结果

由图3可知：增加一条跑道而不特别指定跑道的作用，可以起到更好的效果，使吞吐率进一步提升。图3中显示了WARNING状态，表明开始进行降落队列的清空。

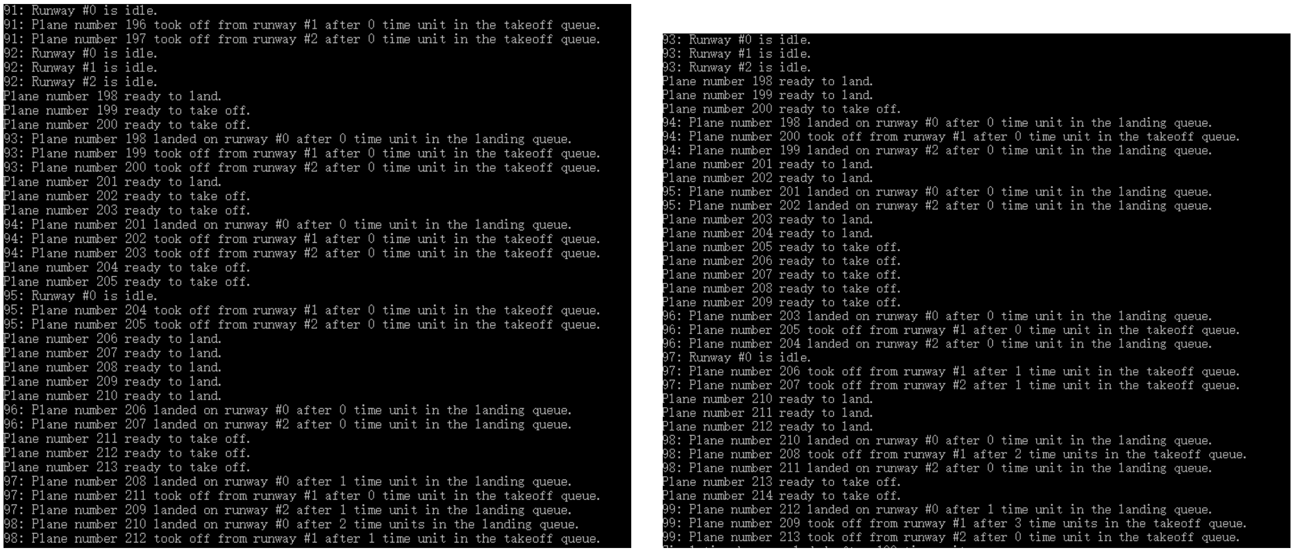


图 4: 问题四实验结果

由图4可知：与问题二的结论类似，需要讨论机场是否达到饱和状态。饱和则新增跑道可增大吞吐量，否则则不行。但考虑到小机场较少飞机的情况，继续增加跑道只会增加成本，使得新增的跑道大多时候处在空闲的状态。

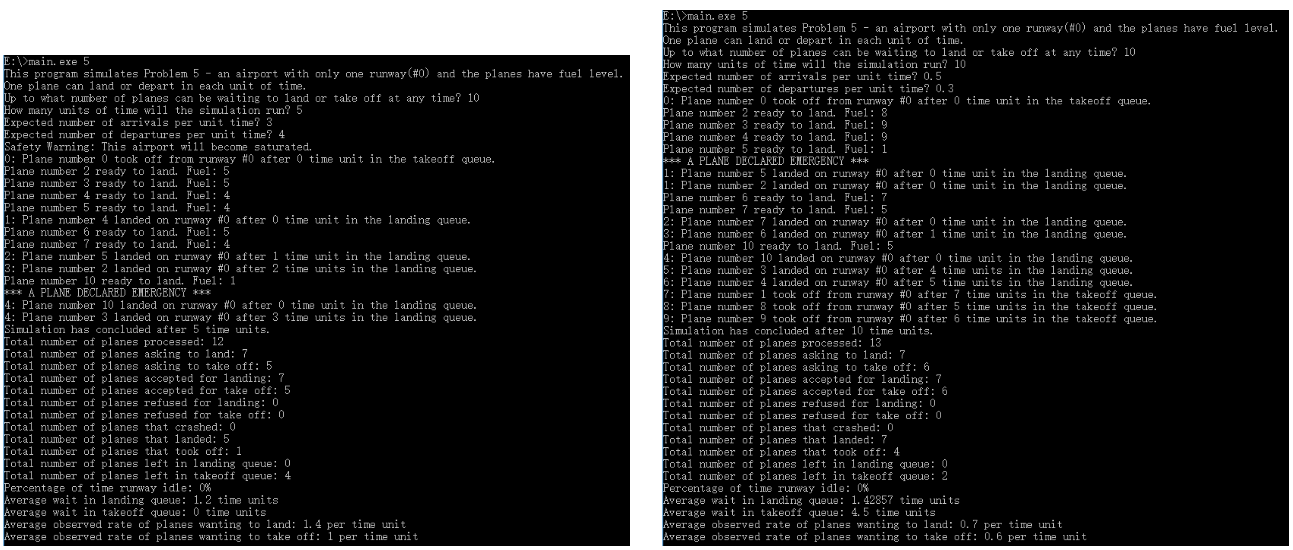


图 5: 问题五实验结果

由图5可知：增加燃油限制，对吞吐量不会有太大影响，仅仅是将普通的队列更改为优先队列而已，先处理优先级较大（燃油量较少）的飞机。同时需要处理好紧急情况(EMERGENCY)，

在图5中出现了这种情况并被我们成功处理，可见我们的程序具有很强的鲁棒性。

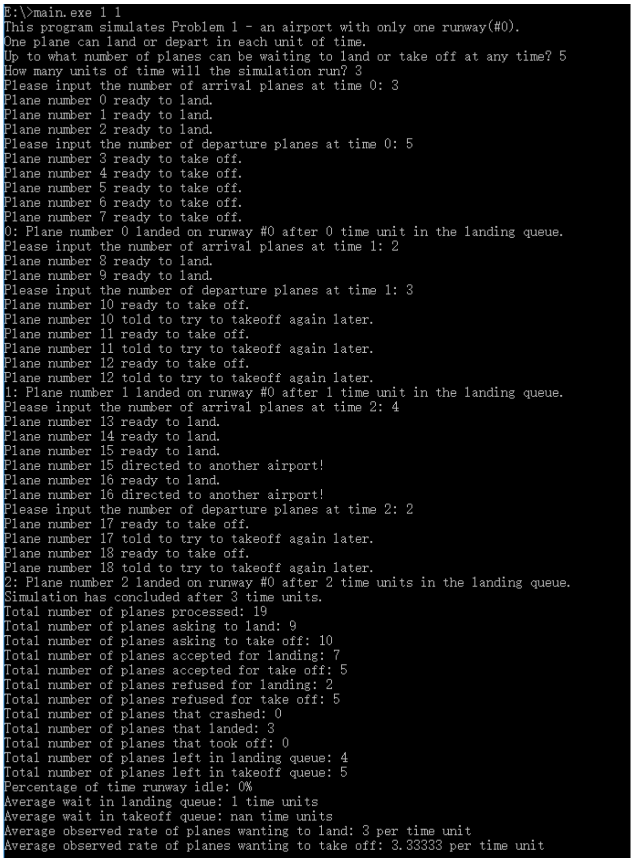


图 6: 问题六实验结果

由图6可知：增加人工输入环节其实会使过程变得更加复杂，每个时刻到达与离去的飞机数目不再符合数学规律，但我们的程序依然能够很好地处理。

4 分工、贡献与自我评分

	分工	贡献度	自我评分
曾天宇	复现书本代码，实现问题一、五，查阅资料，实验报告撰写	0.33	10/10
陈鸿峥	复现书本代码，实现问题二、六，代码整合与测试，修改实验报告	0.33	10/10
黄杨峻	复现书本代码，实现问题三、四，完成实验报告大部分内容	0.33	10/10

5 项目总结

虽然这次项目只是考察基本数据结构队列的使用以及相应的模拟，但如果要作为一个

大项目来做也绝非易事。首先书本中的源代码就非常的长，非常的复杂，一开始需要花费不少时间读懂程序如何运作，而且要非常熟悉每一个函数及代码段的功能，脑力耗费自然也不小。一开始，我们小组还没定好代码编写的风格，最后才决定重构代码并将功能整合，所以前后浪费了不少时间。而且由于是小组作业，组内成员对题目的理解也各有不同，所以对于同一问题，各自的解决思路和代码也不同。到最后整合成一个程序时遇到了不少困难，可能下次做项目的时候要先统一好意见再开始。最好创建一个文档，并新建一个git仓库，共同管理，同时做好代码注释以便组员阅读。

6 程序清单

6.1 主函数

```
#include <iostream>
#include <queue>
#include <vector>
#include <cstring>
#include <algorithm>
#include <time.h>
#include <cmath>
#include "Random.hpp"
#include "Runway.hpp"
using namespace std;

int problem_num;
bool manual_mode = false;

void initialize(int& end_time,int& queue_limit,double& arrival_rate,double& departure_rate)
{
    switch (problem_num)
    {
        case 1:
        cout << "This program simulates Problem 1 - an airport with only one runway(#0)." << endl;
        break;
        case 2:
        cout << "This program simulates Problem 2 - an airport with two runways." << endl
             << "One only for landings(#0) and the other only for takeoffs(#1)." << endl;
        break;
        case 3:
        cout << "This program simulates Problem 3 - an airport with two runways." << endl
             << "One mainly for landings(#0) and the other mainly for takeoffs(#1)." << endl;
        break;
        case 4:
        cout << "This program simulates Problem 4 - an airport with three runways." << endl
             << "One only for landings(#0), the second one only for takeoffs(#1), and the third mainly for landings(#2)." <<
        break;
        case 5:
        cout << "This program simulates Problem 5 - an airport with only one runway(#0) and the planes have fuel level." <<
        break;
        default:
        cerr << "Error: No such problem!" << endl;
        return;
    }
    cout << "One plane can land or depart in each unit of time." << endl;
    cout << "Up to what number of planes can be waiting to land or take off at any time? " << flush;
    cin  >> queue_limit;
    cout << "How many units of time will the simulation run? " << flush;
    cin  >> end_time;
```

```
    if (manual_mode)
        return;
    bool acceptable = false;
    do {
        cout << "Expected number of arrivals per unit time? " << flush;
        cin >> arrival_rate;
        cout << "Expected number of departures per unit time? " << flush;
        cin >> departure_rate;
        if (arrival_rate < 0.0 || departure_rate < 0.0)
            cerr << "These rates must be nonnegative." << endl;
        else
            acceptable = true;
        if (acceptable && arrival_rate + departure_rate > 1.0)
            cerr << "Safety Warning: This airport will become saturated." << endl;
    } while (!acceptable);
}

int main(int argc, const char * argv[]) {
    problem_num = stoi(string(argv[1]));
    if (argc > 2) // the second argv is for Problem 6 (used for debug)
        manual_mode = (stoi(string(argv[2])) == 1 ? 1 : 0);
    int end_time, queue_limit, flight_number=0;
    double arrival_rate, departure_rate;
    initialize(end_time, queue_limit, arrival_rate, departure_rate); // initialize the arrive and depart list
    Random variable; // set the number of planes to takeoff and land

    // initialize the airport and runways
    Runway small_airport(queue_limit);
    if (problem_num == 1 || problem_num == 5)
        small_airport.set_runways(1,
            vector<Runway_mode> {Runway_mode::mainly_landing});
    else if (problem_num == 2)
        small_airport.set_runways(2,
            vector<Runway_mode> {Runway_mode::only_landing,
                                 Runway_mode::only_takeoff});
    else if (problem_num == 3)
        small_airport.set_runways(2,
            vector<Runway_mode> {Runway_mode::mainly_landing,
                                 Runway_mode::mainly_takeoff});
    else if (problem_num == 4)
        small_airport.set_runways(3,
            vector<Runway_mode> {Runway_mode::only_landing,
                                 Runway_mode::only_takeoff,
                                 Runway_mode::mainly_landing});

    // processing
    bool flag_change_status = false;
    for (int current_time = 0; current_time < end_time; current_time++) {
        // generate arrival and departure planes
        int num_arrivals;
        if (!manual_mode)
            num_arrivals = variable.poisson(arrival_rate);
        else
        {
            cout << "Please input the number of arrival planes at time " << current_time << ": ";
            cin >> num_arrivals;
        }

        if (problem_num != 5)
            for (int i = 0; i < num_arrivals; i++) {
                Plane current_plane(flight_number++, current_time, Status::arriving);
                if (small_airport.can_land(current_plane) != true) {
                    current_plane.refuse();
                }
            }
        else {
            vector<Plane> arrival_plane;
            for (int i = 0; i < num_arrivals; i++) {
                Plane current_plane(flight_number++, current_time, Status::arriving, end_time); // end_time-current_time
                arrival_plane.push_back(current_plane);
            }
```

```
            // sort by planes' fuel
            sort(arrival_plane.begin(),arrival_plane.end(),[](const Plane& plane1, const Plane& plane2)
                {return plane1.get_fuel() < plane2.get_fuel();});
            for (int i = 0; i < num_arrivals; i++) {
                if (small_airport.can_land(arrival_plane[i], (problem_num == 5 ? 1 : 0)) != true) {
                    arrival_plane[i].refuse();
                }
            }
        }
        // clear landing backlog
        if (problem_num == 3 && small_airport.landing_full() && !flag_change_status)
        {
            cout << "*** WARNING *** Too many planes arrive! Clear landing backlog..." << endl;
            small_airport.change_runway_status(0,Runway_mode::only_landing);
            small_airport.change_runway_status(1,Runway_mode::only_landing);
            flag_change_status = true;
        }

        int num_departures;
        if (!manual_mode)
            num_departures = variable.poisson(departure_rate);
        else
        {
            cout << "Please input the number of departure planes at time " << current_time << ": ";
            cin >> num_departures;
        }
        for (int j = 0; j < num_departures; j++) {
            Plane current_plane(flight_number++, current_time, Status::departing);
            if (small_airport.can_depart(current_plane) != true) {
                current_plane.refuse();
            }
        }

        // process the planes in the queue
        small_airport.activity(current_time, (problem_num == 5 ? 1 : 0));

        // Problem 3 - clear the backlog
        if  (problem_num == 3 && small_airport.landing_empty() && flag_change_status)
        {
            cout << "*** WARNING *** Landing backlog cleared." << endl;
            small_airport.change_runway_status(0,Runway_mode::mainly_landing);
            small_airport.change_runway_status(1,Runway_mode::mainly_takeoff);
            flag_change_status = false;
        }
    }
    small_airport.shut_down(end_time);
    return 0;
}
```

6.2 Plane类

```
#ifndef PLANE_HPP
#define PLANE_HPP

#include <iostream>
using namespace std;

enum Status {null, arriving, departing};

class Plane{
public:
    Plane(){
        flt_num = -1;
        clock_start = -1;
        state = Status::null;
    }
    Plane(int flt,int time,Status status,int remained_time=-1){
        flt_num = flt;
        clock_start = time;
        state = status;
```

```cpp
        if (remained_time == -1){
            fuel = 0x3f3f3f3f;
            cout << "Plane number " << flt << " ready to ";
            if(status == Status::arriving)
                cout << "land." << endl;
            else
                cout << "take off." << endl;
        } else {
            fuel = rand() % (remained_time+1);
            fuel = (fuel == 0 ? 1 : fuel);
            cout << "Plane number " << flt << " ready to ";
            if(status == Status::arriving)
                cout << "land. Fuel: " << fuel << endl;
            else
                cout << "take off. Fuel: " << fuel << endl;
        }
    }
    int get_fuel() const{
        return fuel;
    }
    void reduce_fuel(){
        fuel--; // can set other functions
    }
    void refuse() const;
    void land(int time,int rw_num) const;
    void fly(int time,int rw_num) const;
    void crash() const;
    int started() const;

private:
    int flt_num;
    int fuel;
    int clock_start;
    Status state;
};

void Plane::crash() const{
    cout << "Plane number " << flt_num << " crashed!" << endl;
}

void Plane::refuse() const{
    cout << "Plane number " << flt_num;
    if (state == Status::arriving)
        cout << " directed to another airport!" << endl;
    else
        cout << " told to try to takeoff again later." << endl;
    // broadcast refuse
}

void Plane::land(int time,int rw_num=0) const{
    // state == Status::arriving
    int wait = time - clock_start;
    cout << time << ": Plane number " << flt_num << " landed on runway #" << rw_num << " after " << wait
         << " time unit" << ((wait <= 1) ? "" : "s")
         << " in the landing queue." << endl;
    // broadcast land & land time
}

void Plane::fly(int time,int rw_num=0) const{
    // state == Status::departing
    int wait = time - clock_start;
    cout << time << ": Plane number " << flt_num << " took off from runway #" << rw_num << " after " << wait
         << " time unit" << ((wait <= 1) ? "" : "s")
         << " in the takeoff queue." << endl;
    // broadcast takeoff & takeoff time
}

int Plane::started() const{
    return clock_start;
}
```

```
#endif // PLANE_HPP
```

6.3 Runway类

```
#ifndef RUNWAY_HPP
#define RUNWAY_HPP

#include <vector>
#include <algorithm>
#include "Plane.hpp"
using namespace std;

//bool value => Error_Code true: success false: fail
enum Runway_activity {idle, land, takeoff};
enum Runway_mode {mainly_landing, mainly_takeoff, only_landing, only_takeoff};

class Runway {
    queue<Plane> landing;
    queue<Plane> takeoff;
    vector<Plane> landing_f;
    int num_runways;
    vector<Runway_mode> runway_mode;
    int num_landing_runways;
    int num_takeoff_runways;

    int queue_limit;
    int num_land_request;
    int num_takeoff_request;
    int num_landings;
    int num_takeoffs;
    int num_land_accepted;
    int num_takeoff_accepted;
    int num_land_refused;
    int num_takeoff_refused;
    int num_crashed;
    int land_wait;
    int takeoff_wait;
    int idle_time;

    Runway_activity land_one_plane(int time,int rw_num);
    Runway_activity takeoff_one_plane(int time,int rw_num);

public:
    Runway(int limit){
        queue_limit = limit;
        num_runways = num_landing_runways = num_takeoff_runways = 1;
        runway_mode.push_back(Runway_mode::mainly_landing);
        num_land_request = num_takeoff_request = num_landings
            = num_takeoffs = num_land_accepted = num_takeoff_accepted
            = num_land_refused = num_takeoff_refused = land_wait
            = takeoff_wait = idle_time = num_crashed = 0;
    }
    void set_runways(int num_rw, vector<Runway_mode> rw_mode){
        num_runways = num_rw;
        runway_mode = rw_mode;
        num_landing_runways = num_takeoff_runways = 0;
        for (auto runway: runway_mode){
            if (runway != Runway_mode::only_takeoff)
                num_landing_runways++;
            if (runway != Runway_mode::only_landing)
                num_takeoff_runways++;
        }
    }

    bool landing_full() const{
        return (landing.size() >= queue_limit);
    }
    bool takeoff_empty() const{
        return takeoff.empty();
```

```
    }
    bool landing_empty() const{
        return landing.empty();
    }
    bool Qlanding_runway() const{
        return (num_landing_runways != 0);
    }
    bool Qtakeoff_runway() const{
        return (num_takeoff_runways != 0);
    }

    bool can_land(const Plane &current,int mode=0){ // mode 0: without considering fuel
        bool result;
        if (landing.size() < queue_limit && Qlanding_runway()) {
            result = true;
            if (mode == 0)
                landing.push(current);
            else
                landing_f.push_back(current);
        } else {
            result = false;
        }
        num_land_request++;
        if (result != true) {
            num_land_refused++;
        } else {
            num_land_accepted++;
        }
        return result;
    }

    bool can_depart(const Plane &current){
        bool result;
        if (takeoff.size() < queue_limit && Qtakeoff_runway()) {
            result = true;
            takeoff.push(current);
        } else {
            result = false;
        }
        num_takeoff_request++;
        if (result != true) {
            num_takeoff_refused++;
        } else {
            num_takeoff_accepted++;
        }
        return result;
    }

    void run_idle(int time, int runway_num = 1)
    {
        idle_time++;
        cout << time << ": Runway #" << runway_num << " is idle." << endl;
    }

    void change_runway_status(int runway_num, Runway_mode rw_mode);

    // modify the original activity
    void activity(int time,int mode);

    void shut_down(int time) const;
};

void Runway::change_runway_status(int runway_num, Runway_mode rw_mode)
{
    if (runway_mode[runway_num] != Runway_mode::only_takeoff)
        num_landing_runways--;
    if (runway_mode[runway_num] != Runway_mode::only_landing)
        num_takeoff_runways--;
    runway_mode[runway_num] = rw_mode;
    if (runway_mode[runway_num] != Runway_mode::only_takeoff)
        num_landing_runways++;
```

```
    if (runway_mode[runway_num] != Runway_mode::only_landing)
        num_takeoff_runways++;
}

Runway_activity Runway::land_one_plane(int time,int rw_num=0)
{
    Plane moving = landing.front();
    land_wait += time - moving.started();
    num_landings++;
    moving.land(time,rw_num); // for plane
    landing.pop();
    return Runway_activity::land;
}

Runway_activity Runway::takeoff_one_plane(int time,int rw_num=0)
{
    Plane moving = takeoff.front();
    takeoff_wait += time - moving.started();
    num_takeoffs++;
    moving.fly(time,rw_num); // for plane
    takeoff.pop();
    return Runway_activity::takeoff;
}

void Runway::activity(int time,int mode=0) // mode 0: without considering fuel
{
    if (mode != 0)
    {
        if (!landing_f.empty())
        {
            sort(landing_f.begin(),landing_f.end(),[](const Plane& plane1, const Plane& plane2)
                {return plane1.get_fuel() < plane2.get_fuel();});
            int index = 0;
            for (auto plane = landing_f.begin(); plane != landing_f.end(); ++plane)
                if (plane->get_fuel() < 0) {
                    index++;
                    plane->crash();
                    num_crashed++;
                } else if (plane->get_fuel() == 1) {
                    cout << "*** A PLANE DECLARED EMERGENCY *** " << endl;
                    land_wait += time - plane->started();
                    plane->land(time);
                    num_landings++;
                    index++; // no break!
                } else {
                    land_wait += time - plane->started();
                    plane->land(time);
                    num_landings++;
                    index++;
                    break;
                }
            // remove the crashed and landed plane
            for (int i = 0; i < index; ++i)
                landing_f.erase(landing_f.begin());
            // reduce the remaining planes' fuel
            for (auto plane = landing_f.begin(); plane != landing_f.end(); ++plane)
                plane->reduce_fuel();
        }
        else if (!takeoff.empty())
            takeoff_one_plane(time);
        else
            run_idle(time,0);
        return;
    }
    Runway_activity in_progress = Runway_activity::idle;
    for (int i = 0; i < num_runways; ++i)
    {
        switch (runway_mode[i])
        {
            case mainly_landing:
                if (!landing.empty())
```

```
                in_progress = land_one_plane(time, i);
            else if (!takeoff.empty())
                in_progress = takeoff_one_plane(time, i);
            break;

        case mainly_takeoff:
            if (!takeoff.empty())
                in_progress = takeoff_one_plane(time, i);
            else if (!landing.empty())
                in_progress = land_one_plane(time, i);
            break;

        case only_landing:
            if (!landing.empty())
                in_progress = land_one_plane(time, i);
            break;

        case only_takeoff:
            if (!takeoff.empty())
                in_progress = takeoff_one_plane(time, i);
            break;
        }
        // current runway does nothing
        if (in_progress == Runway_activity::idle)
            run_idle(time, i);
    }
}

void Runway::shut_down(int time) const
{
    cout << "Simulation has concluded after " << time << " time units." << endl
    << "Total number of planes processed: "
    << (num_land_request + num_takeoff_request) << endl
    << "Total number of planes asking to land: "
    << num_land_request << endl
    << "Total number of planes asking to take off: "
    << num_takeoff_request << endl
    << "Total number of planes accepted for landing: "
    << num_land_accepted << endl
    << "Total number of planes accepted for take off: "
    << num_takeoff_accepted << endl
    << "Total number of planes refused for landing: "
    << num_land_refused << endl
    << "Total number of planes refused for take off: "
    << num_takeoff_refused << endl
    << "Total number of planes that crashed: "
    << num_crashed << endl
    << "Total number of planes that landed: "
    << num_landings << endl
    << "Total number of planes that took off: "
    << num_takeoffs << endl
    << "Total number of planes left in landing queue: "
    << landing.size() << endl
    << "Total number of planes left in takeoff queue: "
    << takeoff.size() << endl
    << "Percentage of time runway idle: "
    << 100.0 * ((float) idle_time) / ((float) time) << "%" << endl
    << "Average wait in landing queue: "
    << ((float) land_wait) / ((float) num_landings) << " time units" << endl
    << "Average wait in takeoff queue: "
    << ((float) takeoff_wait) / ((float) num_takeoffs) << " time units" << endl
    << "Average observed rate of planes wanting to land: "
    << ((float) num_land_request) / ((float) time) << " per time unit" << endl
    << "Average observed rate of planes wanting to take off: "
    << ((float) num_takeoff_request) / ((float) time) << " per time unit" << endl;
}

#endif // RUNWAY_HPP
```

6.4 Random类

```
#ifndef RANDOM_HPP
#define RANDOM_HPP

class Random{
public:
    Random(bool pseudo=true){
        if(pseudo) seed = 1;
        else seed = time(NULL) % 0xFFFFFF;
        multiplier = 2743;
        add_on = 5923;
    }

    double rand_real(){
        double max = 0xFFFFFF;
        double temp = reseed();
        if (temp<0) {
            temp+=max;
        }
        return temp/max;
    }

    int poisson(double rate){
        double limit = exp(-rate);
        double prod = rand_real();
        int count = 0;
        while (prod>limit) {
            count++;
            prod *= rand_real();
        }
        return count;
    }

private:
    int reseed(){
        seed = seed*multiplier + add_on;
        return seed;
    }
    int seed,multiplier,add_on;
};

#endif // RANDOM_HPP
```