МИНИСТЕРСТВО НАУКИ И ВЫСШЕГО ОБРАЗОВАНИЯ
РОССИЙСКОЙ ФЕДЕРАЦИИ

ФЕДЕРАЛЬНОЕ ГОСУДАРСТВЕННОЕ БЮДЖЕТНОЕ
ОБРАЗОВАТЕЛЬНОЕ УЧРЕЖДЕНИЕ ВЫСШЕГО ОБРАЗОВАНИЯ
«БЕЛГОРОДСКИЙ ГОСУДАРСТВЕННЫЙ ТЕХНОЛОГИЧЕСКИЙ УНИВЕРСИТЕТ им. В. Г. ШУХОВА» (БГТУ им. В.Г. Шухова)

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Лабораторная работа №5

по дисциплине: «Исследование операций»

Вариант 23

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Тема: Закрытая транспортная задача

Цель работы: изучить математическую модель транспортной задачи, овладеть методами решения этой задачи

Ход работы:

$$\vec{a} = (21, 22, 22, 20);$$

$$\vec{b} = (18, 20, 19, 19, 9);$$

$$C = \begin{pmatrix} 14 & 27 & 6 & 16 & 8 \\ 2 & 4 & 19 & 4 & 27 \\ 26 & 23 & 1 & 20 & 3 \\ 24 & 5 & 12 & 30 & 5 \end{pmatrix}$$

1. Изучить содержательную и математическую постановки закрытой транспортной задачи, методы нахождения первого опорного решения ее системы ограничений. Изучить понятие цикла пересчета в матрице перевозок. Овладеть распределительным методом и методом потенциалов, а также их алгоритмами.

2. Составить и отладить программы решения транспортной задачи распределительным методом и методом потенциалов.

Написанная библиотека:

```
#include "transport.h"
#include <utility>

TransportTable::TransportTable(Matrix costMatrix, vector<float> stock,
                               vector<float> requests) {
  this->costMatrix = costMatrix;
  this->stock = std::move(stock);
  this->requests = std::move(requests);
  planTable = vector < vector < PlanTableElement >> ();
  for (int row = 0; row < costMatrix.getRows(); row++) {
    planTable.emplace_back(costMatrix.getColumns());
    for (int column = 0; column < costMatrix.getColumns(); column++) {
      planTable[row][column].isBasic = false;
      planTable[row][column].value = 0;
    }
  }
}

void TransportTable::fillTransportTableMinValue() {
  for (int row = 0; row < planTable.size(); row++) {
    for (int column = 0; column < planTable[0].size(); column++) {
      planTable[row][column].isBasic = true;
    }
  }
  vector<float> stockTmp = stock;
  vector<float> requestsTmp = requests;
  bool isFull = false;
  while (!isFull) {
    Position minValuePosition = findMinValuePosition();
    if (fcmp(requestsTmp[minValuePosition.column],
             stockTmp[minValuePosition.row])) {
      planTable[minValuePosition.row][minValuePosition.column].value =
              requestsTmp[minValuePosition.column];
      requestsTmp[minValuePosition.column] = 0;
      stockTmp[minValuePosition.row] = 0;
      for (int row = 0; row < planTable.size(); row++) {
        if (row != minValuePosition.row &&
            planTable[row][minValuePosition.column].value == 0) {
          planTable[row][minValuePosition.column].isBasic = false;
        }
      }
      for (int column = 0; column < planTable.size(); column++) {
        if (column != minValuePosition.column &&
            planTable[minValuePosition.row][column].value == 0) {
          planTable[minValuePosition.row][column].isBasic = false;
        }
      }
    } else if (requestsTmp[minValuePosition.column] <
               stockTmp[minValuePosition.row]) {
      planTable[minValuePosition.row][minValuePosition.column].value =
              requestsTmp[minValuePosition.column];
      stockTmp[minValuePosition.row] -= requestsTmp[minValuePosition.column];
      requestsTmp[minValuePosition.column] = 0;
      for (int row = 0; row < planTable.size(); row++) {
        if (row != minValuePosition.row &&
            planTable[row][minValuePosition.column].value == 0) {
          planTable[row][minValuePosition.column].isBasic = false;
        }
      }
    } else {
      planTable[minValuePosition.row][minValuePosition.column].value =
              stockTmp[minValuePosition.row];
      requestsTmp[minValuePosition.column] -= stockTmp[minValuePosition.row];
      stockTmp[minValuePosition.row] = 0;
      for (int column = 0; column < planTable.size(); column++) {
        if (column != minValuePosition.column &&
            planTable[minValuePosition.row][column].value
            == 0) {
          planTable[minValuePosition.row][column].isBasic = false;
        }
      }
    }
    isFull = checkIfTableIsFull();
  }
}

bool TransportTable::checkIfTableIsFull() {
  for (int row = 0; row < planTable.size(); row++) {
    for (int column = 0; column < planTable[0].size(); column++) {
      if (planTable[row][column].isBasic &&
          fcmp(planTable[row][column].value, 0))
        return false;
    }
  }
  return true;
}

Position TransportTable::findMinValuePosition() {
  Position minValuePosition(0, 0);
  float minValue = INT32_MAX;
  for (int row = 0; row < planTable.size(); row++) {
    for (int column = 0; column < planTable[0].size(); column++) {
      if (planTable[row][column].isBasic &&
          fcmp(planTable[row][column].value, 0)
          && costMatrix.getData(row, column) < minValue) {
        minValuePosition = Position(row, column);
        minValue = costMatrix.getData(row, column);
      }
    }
  }
  return minValuePosition;
}

float TransportTable::countCycleGamma(Sequence cycle) {
  float sum = 0;
  for (int i = 0; i < cycle.positions.size() - 1; i++) {
    float nextValue = costMatrix.getData(cycle.positions[i].row,
                                         cycle.positions[i].column);
    if (i % 2 == 0) {
      sum += nextValue;
    } else {
      sum -= nextValue;
    }
  }
  return sum;
}

Sequence TransportTable::findCycle(Position start) {
  Sequence sequence;
  sequence.positions.push_back(start);
  return _findCycle(sequence, Direction::Any);
}

Sequence TransportTable::_findCycle(Sequence sequence, Direction direction) {
  if (sequence.checkIfCycle()) {
    return sequence;
  } else {
    Position currentPosition = sequence.getPosition(-1);
    if (direction == Direction::Vertical || direction == Direction::Any) {
      //Проход вверх
      while (currentPosition.row >= 0) {
        bool isCurrentPositionInSequence =
                sequence.checkIfPositionInSequence(currentPosition);
        if (getPlanTableElement(currentPosition).isBasic &&
            !isCurrentPositionInSequence ||
            sequence.positions.size() > 2 && currentPosition ==
                                     sequence.positions[0]) {
          Sequence newSequence = sequence;
          newSequence.positions.push_back(currentPosition);
          Sequence resultSequence = _findCycle(newSequence,
                                     Direction::Horizontal);
          if (!resultSequence.isEmpty()) {
            return resultSequence;
          }
        }
        currentPosition.row--;
      }
      //Проход вниз
      currentPosition = sequence.getPosition(-1);
      while (currentPosition.row <= planTable.size() - 1) {
        bool isCurrentPositionInSequence =
                sequence.checkIfPositionInSequence(currentPosition);
        if (getPlanTableElement(currentPosition).isBasic &&
            !isCurrentPositionInSequence ||
            sequence.positions.size() > 2 && currentPosition ==
                                          sequence.positions[0]) {
          Sequence newSequence = sequence;
          newSequence.positions.push_back(currentPosition);
          Sequence resultSequence = _findCycle(newSequence,
                                            Direction::Horizontal);
          if (!resultSequence.isEmpty()) {
            return resultSequence;
          }
        }
        currentPosition.row++;
      }
    }
    if (direction == Direction::Horizontal || direction == Direction::Any) {
      //Проход влево
      currentPosition = sequence.getPosition(-1);
      while (currentPosition.column >= 0) {
        bool isCurrentPositionInSequence =
                sequence.checkIfPositionInSequence(currentPosition);
        if (getPlanTableElement(currentPosition).isBasic &&
            !isCurrentPositionInSequence ||
            sequence.positions.size() > 2 && currentPosition ==
                                          sequence.positions[0]) {
          Sequence newSequence = sequence;
          newSequence.positions.push_back(currentPosition);
          Sequence resultSequence = _findCycle(newSequence,
                                            Direction::Vertical);
          if (!resultSequence.isEmpty()) {
            return resultSequence;
          }
        }
        currentPosition.column--;
      }
      //Проход вправо
      currentPosition = sequence.getPosition(-1);
      while (currentPosition.column <= planTable[0].size() - 1) {
        currentPosition.column++;
        bool isCurrentPositionInSequence =
                sequence.checkIfPositionInSequence(currentPosition);
        if (getPlanTableElement(currentPosition).isBasic &&
            !isCurrentPositionInSequence ||
            sequence.positions.size() > 2 && currentPosition ==
                                          sequence.positions[0]) {
          Sequence newSequence = sequence;
          newSequence.positions.push_back(currentPosition);
          Sequence resultSequence = _findCycle(newSequence,
                                            Direction::Vertical);
          if (!resultSequence.isEmpty()) {
            return resultSequence;
          }
        }
      }
    }
    return {};
  }
}

PlanTableElement TransportTable::getPlanTableElement(Position position) {
  return planTable[position.row][position.column];
}
```

```
void TransportTable::makeShiftByCycle(Sequence cycle, float value) {
  for (int i = 0; i < cycle.positions.size() - 1; i++) {
    Position currentPosition = cycle.getPosition(i);
    if (i % 2 == 0) {
      planTable[currentPosition.row][currentPosition.column].value += value;
    } else {
      planTable[currentPosition.row][currentPosition.column].value -= value;
    }
  }
}

bool Sequence::checkIfCycle() {
  for (int i = 0; i < positions.size() - 1; i++) {
    if (positions[i].row != positions[i + 1].row &&
        positions[i].column != positions[i + 1].column) {
      return false;
    }
  }
  return positions.size() > 1 && positions[0] == positions[positions.size() - 1];
}

void Sequence::addPosition(Position position) {
  positions.push_back(position);
}

Position Sequence::getPosition(int index) {
  if (index >= 0)
    return positions[index];
  else {
    return positions[positions.size() + index];
  }
}

bool Sequence::isEmpty() {
  return positions.empty();
}

bool Sequence::checkIfPositionInSequence(Position target) {
  for (int i = 0; i < positions.size(); i++) {
    if (positions[i] == target)
      return true;
  }
  return false;
}

bool Position::operator==(Position other) {
  return this->row == other.row && this->column == other.column;
}
```

Реализация распределительного метода:

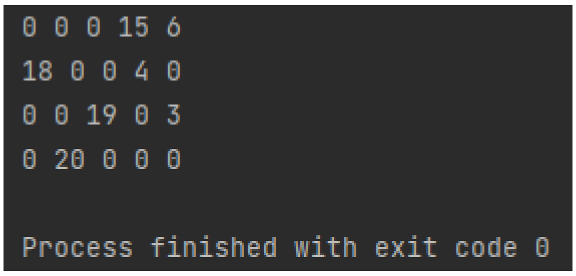
```
void TransportTable::solveByDistributiveMethod() {
  fillTransportTableMinValue();
  bool foundSolution = false;
  while (!foundSolution) {
    float minGamma = INT32_MAX;
    Sequence cycleWithMinValue;
    for (int i = 0; i < planTable.size(); i++) {
      for (int j = 0; j < planTable[0].size(); j++) {
        std::cout << planTable[i][j].value << " ";
```

```
   }
   std::cout << "\n";
  }
  std::cout << "\n";
  for (int row = 0; row < planTable.size(); row++) {
   for (int column = 0; column < planTable[0].size(); column++) {
    if (!planTable[row][column].isBasic) {
     Sequence currentCycle = findCycle({row, column});
     float cycleGamma = countCycleGamma(currentCycle);
     if (cycleGamma < minGamma) {
      minGamma = cycleGamma;
      cycleWithMinValue = currentCycle;
     }
    }
   }
  }
  if (minGamma < 0 && !fcmp(minGamma, 0)) {
   float minAmongNegative = INT32_MAX;
   Position positionOfMinAmongNegative{-1, -1};

   for (int i = 1; i < cycleWithMinValue.positions.size() - 1; i += 2) {
    float currentValueWithNegativePosition =
        getPlanTableElement(cycleWithMinValue.getPosition(i)).value;
    if (currentValueWithNegativePosition < minAmongNegative) {
     minAmongNegative = currentValueWithNegativePosition;
     positionOfMinAmongNegative = cycleWithMinValue.getPosition(i);
    }
   }
   makeShiftByCycle(cycleWithMinValue, minAmongNegative);
   planTable[positionOfMinAmongNegative.row][positionOfMinAmongNegative.column].isBasic = false;
   planTable[cycleWithMinValue.getPosition(0).row][cycleWithMinValue.getPosition(0).column].isBasic = true;
  } else {
   foundSolution = true;
  }
 }
}
void TransportTable::fillPotentialsColumn(vector<Potential> &rows,
                     vector<Potential> &columns, int column) {
 for (int row = 0; row < rows.size(); row++) {
  if (planTable[row][column].isBasic && !rows[row].isSet) {
   rows[row].value = costMatrix.getData(row, column) -
            columns[column].value;
   rows[row].isSet = true;
   fillPotentialsRow(rows, columns, row);
  }
 }
}
void TransportTable::fillPotentialsRow(vector<Potential> &rows, vector<Potential>
&columns, int row) {
 for (int column = 0; column < columns.size(); column++) {
  if (planTable[row][column].isBasic && !columns[column].isSet) {
   columns[column].value = costMatrix.getData(row, column) -
               rows[row].value;
   columns[column].isSet = true;
   fillPotentialsColumn(rows, columns, column);
  }
 }
}
```

содержимое файла main.cpp:

```cpp
#include <iostream>
#include "libs/matrix/matrix.h"
#include "libs/transport/transport.h"

int main() {
  Matrix costMatrix;
  costMatrix.inputMatrix(4, 5, {
          {14, 27, 6,  16, 8},
          {2,  4,  19, 4,  27},
          {26, 23, 1,  20, 3},
          {24, 5,  12, 30, 5}
  });
  vector<float> stock{21, 22, 22, 20};
  vector<float> requests{18, 20, 19, 19, 9};
  TransportTable transportTable(costMatrix, stock, requests);
  transportTable.solveByDistributiveMethod();
  for (int i = 0; i < transportTable.planTable.size(); i++) {
    for (int j = 0; j < transportTable.planTable[0].size(); j++) {
      std::cout << transportTable.planTable[i][j].value << " ";
    }
    std::cout << "\n";
  }
}
```

Результат работы программы:



```
0 0 0 15 6
18 0 0 4 0
0 0 19 0 3
0 20 0 0 0

Process finished with exit code 0
```

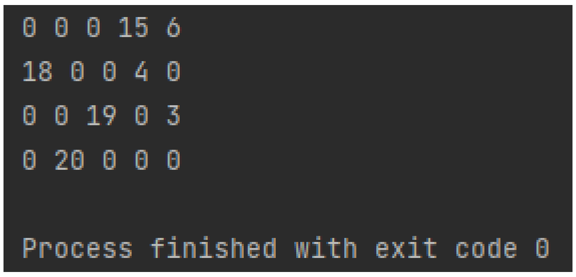
Реализация метода потенциалов:

```cpp
void TransportTable::solveByPotentialMethod() {
  fillTransportTableMinValue();
  bool foundSolution = false;
  while (!foundSolution) {
    vector<Potential> stockPotentials(stock.size());
    vector<Potential> requestPotentials(requests.size());
    for (auto potential: stockPotentials) {
      potential.isSet = false;
    }
    for (auto potential: requestPotentials) {
      potential.isSet = false;
    }
    requestPotentials[0].value = 0;
    requestPotentials[0].isSet = true;
    fillPotentialsColumn(stockPotentials, requestPotentials, 0);
    float minPotentialValue = INT32_MAX;
    Position minPotentialPosition{-1, -1};
    for (int row = 0; row < costMatrix.getRows(); row++) {
      for (int column = 0; column < costMatrix.getColumns(); column++) {
        float currentPotential = costMatrix.getData(row, column) -
                                 (stockPotentials[row].value +
                                requestPotentials[column].value);
        if (currentPotential < minPotentialValue) {
          minPotentialValue = currentPotential;
          minPotentialPosition = Position {row, column};
        }
      }
    }
    if (minPotentialValue < 0 && !fcmp(minPotentialValue, 0)) {
      Sequence cycleWithMinValue = findCycle(minPotentialPosition);
      float minAmongNegative = INT32_MAX;
      Position positionOfMinAmongNegative{-1, -1};
      for (int i = 1; i < cycleWithMinValue.positions.size() - 1; i += 2) {
        float currentValueWithNegativePosition =
                getPlanTableElement(cycleWithMinValue.getPosition(i)).value;
        if (currentValueWithNegativePosition < minAmongNegative) {
          minAmongNegative = currentValueWithNegativePosition;
          positionOfMinAmongNegative = cycleWithMinValue.getPosition(i);
        }
      }
      makeShiftByCycle(cycleWithMinValue, minAmongNegative);
      planTable[positionOfMinAmongNegative.row][positionOfMinAmongNegative.column].isBasic = false;
      planTable[cycleWithMinValue.getPosition(0).row][cycleWithMinValue.getPosition(0).column].isBasic = true;
    } else {
      foundSolution = true;
    }
  }
}
```

содержимое файла main.cpp:

```
#include <iostream>
#include "libs/matrix.h"
#include "libs/transport/transport.h"
int main() {
  Matrix costMatrix;
  costMatrix.inputMatrix(4, 5, {
          {14, 27, 6, 16, 8},
          {2, 4, 19, 4, 27},
          {26, 23, 1, 20, 3},
          {24, 5, 12, 30, 5}
  });
  vector<float> stock{21, 22, 22, 20};
  vector<float> requests{18, 20, 19, 19, 9};
  TransportTable transportTable(costMatrix, stock, requests);
  transportTable.solveByPotentialMethod();
  for (int i = 0; i < transportTable.planTable.size(); i++) {
    for (int j = 0; j < transportTable.planTable[0].size(); j++) {
      std::cout << transportTable.planTable[i][j].value << " ";
    }
    std::cout << "\n";
  }
}
```

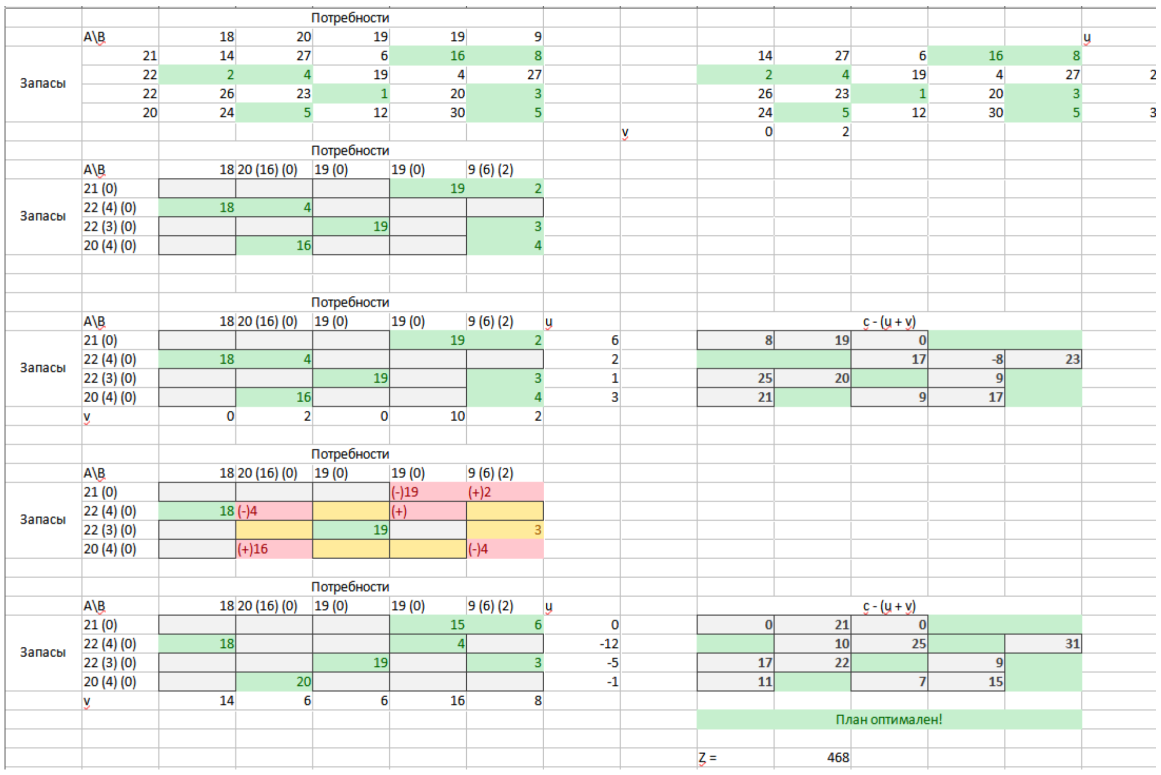
Результат работы программы:



```
0 0 0 15 6
18 0 0 4 0
0 0 19 0 3
0 20 0 0 0

Process finished with exit code 0
```

3. Для подготовки тестовых данных решить вручную одну из следующих ниже задач.

$$\vec{a} = (21, 22, 22, 20);$$
$$\vec{b} = (18, 20, 19, 19, 9);$$
$$C = \begin{pmatrix} 14 & 27 & 6 & 16 & 8 \\ 2 & 4 & 19 & 4 & 27 \\ 26 & 23 & 1 & 20 & 3 \\ 24 & 5 & 12 & 30 & 5 \end{pmatrix}$$



				Потребности										
	A\B	18	20	19	19	9								u
Запасы	21	14	27	6	16	8			14	27	6	16	8	
	22	2	4	19	4	27			2	4	19	4	27	2
	22	26	23	1	20	3			26	23	1	20	3	
	20	24	5	12	30	5			24	5	12	30	5	3
								v	0	2				
				Потребности										
	A\B	18	20 (16) (0)	19 (0)	19 (0)	9 (6) (2)								
Запасы	21 (0)				19	2								
	22 (4) (0)	18	4											
	22 (3) (0)			19		3								
	20 (4) (0)		16			4								
				Потребности										
	A\B	18	20 (16) (0)	19 (0)	19 (0)	9 (6) (2)	u				c - (u + v)			
Запасы	21 (0)				19	2	6		8	19	0			
	22 (4) (0)	18	4				2				17	-8	23	
	22 (3) (0)			19		3	1		25	20		9		
	20 (4) (0)		16			4	3		21		9	17		
	v	0	2	0	10	2								
				Потребности										
	A\B	18	20 (16) (0)	19 (0)	19 (0)	9 (6) (2)								
Запасы	21 (0)				(-)19	(+)2								
	22 (4) (0)	18	(-)4		(+)									
	22 (3) (0)			19		3								
	20 (4) (0)		(+)16			(-)4								
				Потребности										
	A\B	18	20 (16) (0)	19 (0)	19 (0)	9 (6) (2)	u				c - (u + v)			
Запасы	21 (0)				15	6	0		0	21	0			
	22 (4) (0)	18			4		-12			10	25		31	
	22 (3) (0)			19		3	-5		17	22		9		
	20 (4) (0)		20				-1		11		7	15		
	v	14	6	6	16	8								
											План оптимален!			
									Z =	468				

Вывод: в ходе лабораторной работы мы изучили методы решения закрытой транспортной задачи; реализовали заполнение исходной таблицы методом наименьшей стоимости, решение задачи методом потенциалов и распределительным методом