

---

## GRAVITY LOCATION MODEL IN SUPPLY CHAIN

**Petya Stoyanova, Izabela Pluta**  
[pstoyanova@vtu.bg](mailto:pstoyanova@vtu.bg); [izabelapluta@op.pl](mailto:izabelapluta@op.pl)

*Todor Kableshkov University of Transport*  
*Sofia, st. Geo Milev – 158*  
**BULGARIA**

**Key words:** *supply chain, gravity location model, transport and logistic*

**Abstract:** *The Gravity Location Model is specifically optimization model of Supply chain management /SCM/. The Gravity Location Model is mathematical technique used in supply chain management to determine the optimal location for facilities such as warehouse, distribution center and manufacturing plant. The Gravity Location Model takes into account three main components the origin point, the destination point, and the transportation cost or distance between them. By analyzing these factors, the model can calculate the best location or facility to minimize the transportation cost and improve operational efficiency. Distribution networks and transportation allow product to move from manufacture location to the customer location that is often limited by long distances. Therefore, the ability to manage distribution networks today is a component of competitive advantage that is very important for many industries. To distribute a product, a company certainly needs to decide the fastest and the most inexpensive route. In determining a distribution route, pickup vehicle capacity and labor cost must also be considered by the company. With the optimal distribution route, the company not only minimize distribution costs but also increase customer satisfaction with on-time delivery. In addition to the distribution route, the location of a strategic distribution center must also be considered by the company about its proximity to distribution locations or market.*

### INTRODUCTION

The role of distribution network and transportation is very vital, as described in [1]. Distribution networks and transportation allow products to move from manufacture location to the customer location that is often limited by long distances. The ability to deliver the product to the customer on time, in the right amount and in good condition will determine whether the product will ultimately be competitive in the market. Therefore, the ability to manage distribution networks today is a component of competitive advantage that is very important for many industries. To distribute a product, Company certainly need to decide the fastest and the most inexpensive route. In determining a distribution route, pickup vehicle capacity and labor cost must also be considered by the company. With the optimal distribution route, the company not only minimize distribution costs but also increase customer satisfaction with on-time delivery. In addition to the distribution route, the location of a strategic distribution center must also be considered by the company about its proximity to distribution locations or market. Generally, the problems of scheduling and determining delivering route can have several objectives to be achieved, such as the aim to minimize

delivering costs, minimize delivering time or minimize distance. In mathematical programming, one of these objectives can be an objective function and the other becomes a constraint function. For example, the objective function is to minimize delivering costs, but there are time window constraints, the maximum distance for each vehicle, vehicle capacity or other constraints.



Fig. 1 Supply chain management [2]

The Gravity Location Model is mathematical technique used in supply chain management to determine the optimal location for facilities such as warehouse, distribution center and manufacturing plant;

The Gravity Location Model takes into account three main components the origin point, the destination point, and the transportation cost or distance between them.

Significant Benefits of Utilizing the Center of Gravity Method:

**Cost Reduction:** Businesses can minimize transportation costs by strategically locating distribution centers using the center of gravity method, resulting in significant savings.

**Enhanced Customer Service:** Proximity to customers translates into shorter lead times and faster deliveries. This method enables businesses to improve service levels and boost customer satisfaction.

**Flexibility and Expansion:** It assists network redesign and facilitates geographic expansion planning. It also empowers businesses to adapt to evolving market conditions and ensure their distribution networks remain agile.

**Risk Mitigation:** Diversifying distribution center locations reduces supply chain risks. By spreading facilities across regions, businesses can minimize the impact of disruptions, ensuring continuity of operations.

How the Model Works [3]:

**Data Collection-** The first step is to gather the necessary, up-to-date, and accurate data. This includes information on customer locations, demand volumes, transportation costs, and more. Also, having these pieces of information help in utilizing the center of gravity method efficiently.

**Geocoding-** After collecting the necessary data, the next step is to geocode. This process involves converting customer addresses into geographical coordinates to calculate distances accurately.

Weighted Calculation- Assigning weights to customers based on their importance or demand volume is the next step. These weights reflect the significance of each location within the network. For instance, a customer with higher demand may have a weight assigned to it.

Distance Calculation- The next line of action is to calculate the distance between each customer location and potential distribution center locations. This involves using the geographic coordinates obtained from the geocoding step. You can measure the distance between these two locations using mathematical formulas, such as Pythagoras' theorem.

Calculate the Center of Gravity- The heart of the process lies in calculating the center of gravity itself. This involves taking the weighted average of the latitude and longitude coordinates of the customers, considering the demand weights assigned to each location.

As an example, the model is presented, which is described in [4].

Excel example:

## **1. SELECTION OF A LOCATION FOR ESTABLISHING A PRODUCTION CENTER OF THE COMPANY**

*1.1. Representation of sources, regional centers and consumers in the two-dimensional coordinate system, through the values of the coordinates x and y. It has been established that the following types of points are located on the territory of the settlement:*

- 4 pcs. sources (suppliers of raw materials), designated as S1, S2, S3, S4;
- 3 pcs. regional centers (offices and warehouses), designated as RC1, RC2, RC3;
- 3 pcs. consumers (retailers), designated as R1, R2, R3;

Each of the points is represented in the plane of a two-dimensional coordinate system as a point with coordinates (xi;yi).

The abscissa is plotted with the values of xi, and the ordinate is plotted with the values of yi at the corresponding points and with the values of x and y at the production center.

*1.2. Determining the location of the company's production center.*

The air distance from each point to the production center, which before determining its optimal location is located at the origin of the coordinate system with coordinates (0;0) according to the formula:

$$(1.1) \quad d_i = \sqrt{(x - x_i)^2 + (y - y_i)^2}, \text{ km,}$$

where:

(x;y) - the coordinates of the RC;

(xi;yi) - coordinates of the corresponding points.

We take into account the non-linearity of the existing transport network, taking into account the influence of the coefficient non-linearity.

$$(1.2) \quad C_{nl} = d_i \cdot TN / d_i;$$

(1.3)  $d_i \cdot TN = d_i \cdot C_{nl}$ , km - actual distance along the transport network from each of the raw material supplier points, regional centers and retailers to the production center. Through

these distances and the set transportation tariffs  $C_i$ , those values of the coordinates  $x$  and  $y$  of the RC were found, at which the minimum of the sum of the realized costs when delivering raw materials from the sources to the RC and of finished products from it to the RC is achieved according to the formula:

$$(1.4) \quad C_{opt} = \sum_{i=1}^n d_{iTM} \cdot C_i \rightarrow \min, \frac{\text{руб.}}{\text{мес}}$$

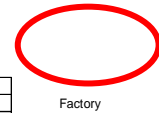
- delivery costs Using the SUMPRODUCT function, we find the optimal value of the delivery costs  $C_{opt}$ , and using the "Solver" functionality in the MS Excel office applications, those values of the coordinates  $x$  and  $y$  of the RC were found, at which it is located at an optimal distance from the regional centers RC.

### Before solving the problem

Cnl	nodes of the transportation network	Tariff for transportation	coordinates		Distance to RC direct	Distance to RC of the transportation network
		$C_i, \text{руб./мес.км}$	$x_i$	$y_i$	$d_{i, \text{дир}}$	$d_{i, \text{сст}}$
sources (suppliers of raw materials)	S1	0,85	-54	-60	80,7	96,9
	S2	0,90	-36	120	125,3	150,3
	S3	0,95	60	12	61,2	73,4
	S4	0,80	120	120	169,7	203,6
regional centers (offices and warehouses)	RC1	1,00	-60	30	67,1	80,5
	RC2	1,00	12	-30	32,3	38,8
	RC3	1,00	66	90	111,6	133,9
consumers (retailers)	R1	1,50	-30	-30	42,4	50,9
	R2	1,50	-12	90	90,8	109,0
	R3	1,50	90	-60	108,2	129,8

$$d_i = \sqrt{(x-x_i)^2 + (y-y_i)^2}, \text{ км}$$

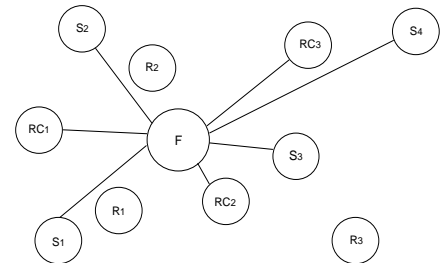
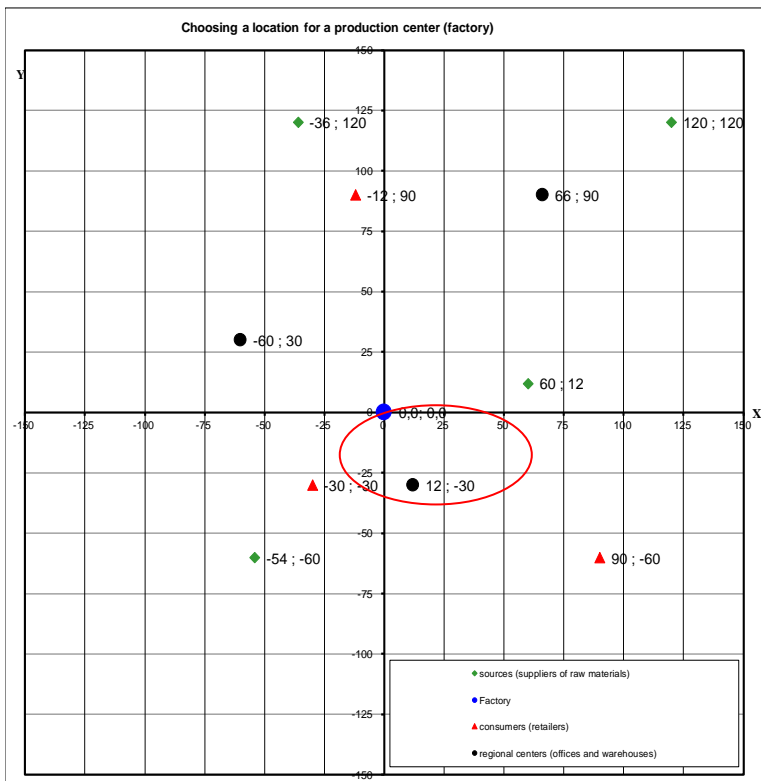
$x^* =$	0,0
$y^* =$	0,0
minimum transportation costs $C_{opt} =$	703,51



$$C_{nl} = d_{iTN} / d_i$$

$$d_{iTN} = d_i \cdot C_{nl}$$

$$C_{opt} = \sum_{i=1}^n d_{iTM} \cdot C_i \rightarrow \min, \frac{\text{руб.}}{\text{мес}}$$



## After solving the problem

Cn/	nodes of the transportation network	Tarif for transportation	coordinates		Distance to RC direct	Distance to RC of the transportation network
		$C_{i,j}$ distance cost	$x_i$	$y_i$	$d_{i,RC}$	$d_{i,RC}^{TN}$
1,20	S1	0,85	-54	-60	116,3	139,5
	S2	0,90	-36	120	104,1	124,9
	S3	0,95	80	12	46,0	55,2
	S4	0,90	120	120	135,1	162,2
regional centers (offices and warehouses)	RC1	1,00	80	30	78,2	93,8
	RC2	1,00	12	-30	61,4	73,7
	RC3	1,00	66	90	75,8	91,0
consumers (retailers)	R1	1,50	-30	-30	77,8	93,4
	R2	1,50	-12	90	66,2	79,4
	R3	1,50	90	-60	116,0	139,2

$$d = \sqrt{(x-x_i)^2 + (y-y_i)^2} \cdot \alpha_{i,j}$$

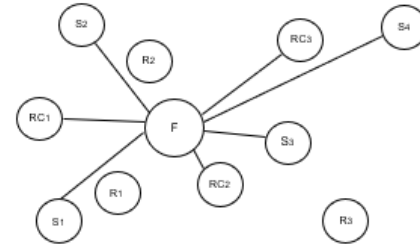
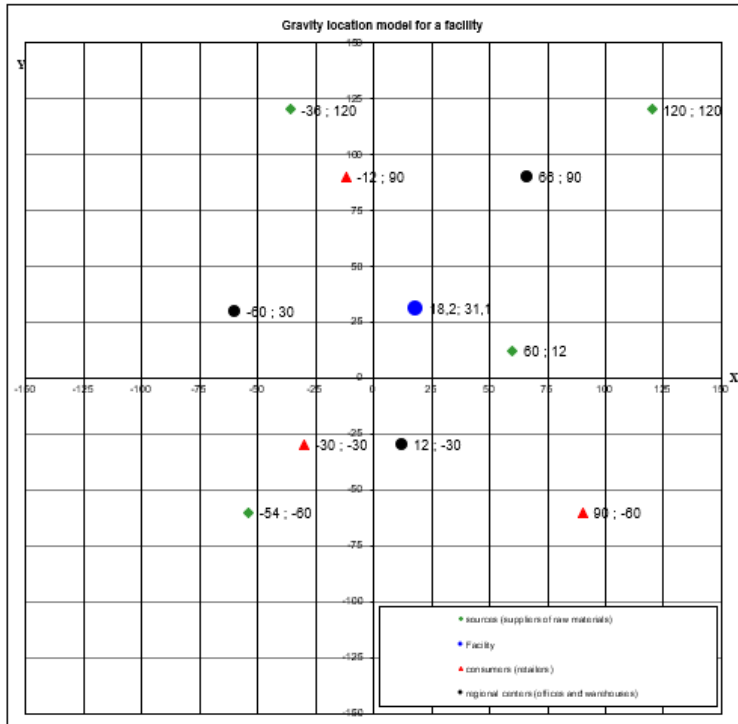
$x^* =$	18,2
$y^* =$	31,1
minimum transportation costs	
$C_{opt} =$	871,73

Facility

$$C_{n1} = d_i \cdot TN / d_i$$

$$d_i \cdot TN = d_i \cdot C_{n1}$$

$$C_{opt} = \sum_{i=1}^n d_{i,F} \cdot C_i \rightarrow \min; \frac{\partial C}{\partial x}$$



## CONCLUSION

The model has been an empirical success in that it accurately predicts trade flows between countries for many goods and services, however a gravity relationship can arise in almost any trade model that includes trade costs that increase with distance. The gravity model in economics was until relatively recently an intellectual orphan, unconnected to the rich family of economic theory. This review is a tale of the orphan's reunion with its heritage and the benefits that have flowed from it. Gravity has long been one of the most successful empirical models in economics. Among these, price level and exchange rate variables have been shown to have a relationship in the gravity model that accounts for a significant amount of the variance not explained by the basic gravity equation. Incorporating the theoretical foundations of gravity into recent practice has led to a richer and more accurate estimation and interpretation of the spatial relations described by gravity.

Distribution broadly defined consumes a very large share of the world's resources and gravity has proven to be the most generally useful empirical model for understanding the distribution of goods and factors of production. It appears to work well at almost any scale. The structural modeling of gravity imposes trade separability, permitting gravity modules to be nested inside a wide range of general equilibrium superstructures. Future work with simulation models may suggest which of many candidate general equilibrium production models do better. [5]

## REFERENCES:

- [1] Stavri Dimitri Dimitrov, Avishai Ceder, A method of examining the structure and topological properties of public-transport networks, Physica A Statistical Mechanics and its Applications, February 2016, DOI: [10.1016/j.physa.2016.01.060](https://doi.org/10.1016/j.physa.2016.01.060)
- [2]<https://www.bing.com/videos/riverview/relatedvideo?q=supply+chain&mid=D5E6AACA5F023E625B2ED5E6AACA5F023E625B2E&FORM=VIRE;>
- [3]<https://www.bing.com/videos/riverview/relatedvideo?q=location+model&mid=B81656CCE605594E10AAB81656CCE605594E10AA&mmscn=mtsc&aps=10&FORM=VRDGAR;>
- [4] Zerom D., Drezner Z., Data-guided Gravity Model for Competitive Facility Location, Networks and Spatial Economics, March 2024, DOI: [10.1007/s11067-024-09623-5](https://doi.org/10.1007/s11067-024-09623-5);
- [5] James E. Anderson, Sanjaya A., Sembiring A. and Willyanto W., Determination of the optimal distribution centre location with gravity location model, 4th Annual Applied Science and Engineering Conference, Journal of Physics: Conference Series 1402 (2019) 022041, DOI: [10.1088/1742-6596/1402/2/022041](https://doi.org/10.1088/1742-6596/1402/2/022041);

## МОДЕЛ НА ГРАВИТАЦИОННО МЕСТОПОЛОЖЕНИЕ ВЪВ ВЕРИГАТА НА ДОСТАВКИ

Петя Стоянова, Изабела Плуца  
[pstoyanova@vtu.bg](mailto:pstoyanova@vtu.bg); [izabelapluta@op.pl](mailto:izabelapluta@op.pl)

*Висше транспортно училище „Тодор Каблешков“,  
София, ул. „Гео Милев“ № 158,  
РЕПУБЛИКА БЪЛГАРИЯ*

**Ключови думи:** верига на доставки, гравитационен модел за локация, транспорт, логистика

**Резюме:** Гравитационният модел за локация е оптимизационна техника, широко използвана в управлението на веригата на доставки (SCM) за определяне на оптималното местоположение на ключови съоръжения като складове, дистрибуционни центрове и производствени бази. Този математически модел оценява три основни компонента: начална точка, крайна точка и транспортни разходи или разстояние между тях. Чрез анализ на тези фактори, моделът определя най-ефективното местоположение, което минимизира транспортните разходи и подобрява цялостната оперативна ефективност.

В рамките на веригите на доставки продуктите трябва да бъдат транспортирани от мястото на производство до клиентите — често на големи разстояния. Ефективното управление на дистрибуционните мрежи се превръща в ключово конкурентно предимство за много индустрии. Компаниите трябва да определят не само най-рентабилния, но и най-бързия дистрибуционен маршрут. При планирането на тези маршрути е необходимо да се вземат предвид капацитетът на превозните средства и разходите за труд.

Оптимизираният дистрибуционен маршрут не само намалява разходите, но и гарантира навременна доставка, което води до повишена удовлетвореност на клиентите. Освен това стратегическото разполагане на дистрибуционни центрове — с оглед на тяхната близост до пазарите и точките на търсене — е от съществено значение за ефективната логистика. Гравитационният модел за локация подпомага вземането на решения в тези области, допринасяйки за по-отзивчива и рентабилна верига на доставки.