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Minimization of Delivery Time in E-Commerce and the Impact on the Global Value Chain

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Abstract

In recent years, we observe that the robots are appearing in the world of logistics. The robotization of the supply chain represents undoubtedly one of the most effective ways to meet the challenges of the digitalization of trade and its consequences on the logistics chain. In this article, we model and we simulate the collective motion of robots in large storage warehouses. At the first time, we start by studying the Vicsek model and we try to expand this model, to add another zone of motion. Vicsek et al. in their simple model, they consider only the orientation zone of motion for each robot in the two-dimensional space. In this paper, we include a second zone of interaction named zone of repulsion R_1, where each robot attempts to maintain a minimum distance from the others. Our interest in this paper is to study, the effect to broaden the repulsion zone R_1 and the orientation zone R_2 on the motion of robots as a function of noise η and density ρ, and to define from which the critical value of these zones R_{1c} and R_{2c} we can have an ordered motion. After the analysis of our results we describe the impact of our study on the storage management, the minimization of delivery time to customers and how we can integrate the complexity of the rise of global value chains for emerging countries. This investigation is performed over different situations via a numerical simulation. Implications of these findings are discussed.

Keywords: Supply chain; Global value chains; Collective motion; Robot motion

Introduction

From the industrial revolution, the machines have not stopped improving to be able to perform repetitive tasks, difficult or impossible for humans in the logistics chain. This is called industrial intelligence [1]. The companies of e-commerce such as Amazon, Ali express, Alibaba etc., have implanted in their distribution centers the robots in the interest to increase the productivity and reduce delivery times [2,3]. We have seen some companies who work with the smart robot and automate many of their warehouse systems to reduce human labor costs and headcount, whilst improving efficiency and reducing mistakes [4]. The robots are settling henceforth, all along in the supply chain [5]. In this research, we will study the distribution of these robots on the surface of warehouses, and the effect of its motion on the delivery time [6,7]. We describe implicitly, the impact of insertion the technological and organizational innovations, on small-large companies and on the emerging countries to facilitate their insertion in the global value chain. To begin this investigation, we use the model of Vicsek et al. [8]. This model is practically simple; because it allows us to model and simulate the motion of a complex system as the movement of robots in a warehouse. The Vicsek model study the collective and complex motion of robots in a two-dimensional space. They treated the problem with computer simulation (information system). In this context, the robots move synchronously in the only zone of orientation R_2 with a constant module of velocity. At each time step the robots take the average direction of motion of robots with a random perturbation introduced, which is the noise. The modeling of these systems far from equilibrium tends to be very complex and depends on many variables and different parameters, because the movement of robots in the warehouses is controlled not only by certain external fields, but with the interactions with other robots in their neighbourhood. In our study we will take in consideration the model of Vicsek and afterward we will try to extend it by adding a new zone of interaction. This zone is named the repulsion zone [9-18]. We are interested in studying also the effect of enlarging these zones of motion on the velocity of robots, which is projected to increase the production. Then we search from which critical value of the interaction zones R_{1c} and R_{2c}, we can have a disorderly or orderly motion. We show after, how R^*_{2c} varies exponentially and depending of the radius of repulsion R_1. The analysis of our results allows us to manage the logistics chain which implemented by robot system; and to understand several complications in the global value chain. The organization of this document is as follows: In the second Section, we describe the model used in our study. In the third section we discuss the numerical results and we end by making some general remarks and by summarizing the main conclusion.

The Mathematical Model and the Algorithm

The suggested model studies the effect of each zone around each robot, where we attempt to maintain a minimum distance between itself and others at all time. Understanding this phenomenon is important in order to be able to control for example the delivery time in interest to satisfy consumers and offer them an ever shorter wait. The rapidity of deliveries has great effect on the annual turnover of the company, what is projected on the country's economy and international trade. Consequently, in order to understand more the motion of behaviour of non-equilibrium multi-robot system, we will extend the Vicsek model [8], by considering in this paper two zones that are defined by two concentric circles ($R_1 \ll R_2$) around every robot [9]. Figures 1-3 represent an example of robot motion in the storage center. Each robot

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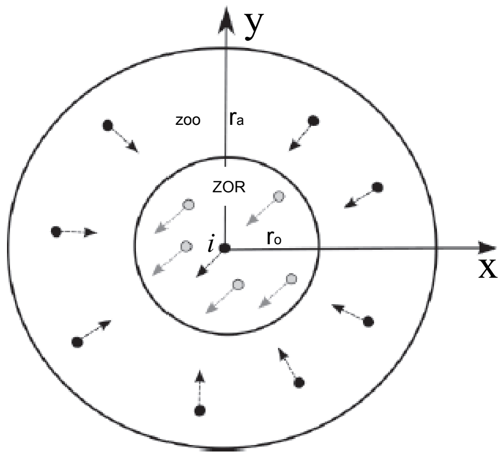

Figure 1: Schematic representation of the two zones centered at the position of the robot j: ZOR is the zone of repulsion R_1 while ZOO is the zone of orientation R_2.

Figure 2: Illustration of motion of robot in the warehouse, they can carry stock of products independently.

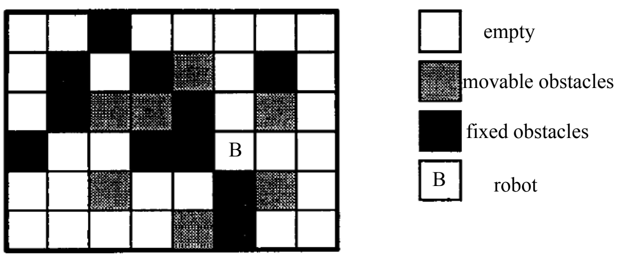

Figure 3: Model of robot motion in a discrete warehouse with the presence of obstacles [2].

is assigned a position, direction and velocity. Our model is formulated in the algorithm.

The model we consider here is the Vicsek model with repulsive interaction that we added. We simulate the behaviour of motion of robot on the 2D environment. We consider an $L \times L$ square shaped surface with periodic boundary conditions. We consider N identical point-wise robot moving at discrete time-steps Δt, by some fixed velocity v_0. We denote by $\vec{v}_j$ the velocity of the robot j and its direction of motion is given by $\vec{d}_j(t)$:

$$\left|\vec{v}_j\right| = v_0 \text{ and } \vec{d}_j(t) = \frac{\vec{v}_j}{v_0} \tag{1}$$

For each robot j, let N_1 (resp. N_2) be the number of the other robots within the zone of repulsion (resp. zone of alignment) at time t (Figures 1-3). We denote by $\vec{r}_{ji}$ the distance vector from the robot j to robot i.

Algorithm

//The direction of motion of robot j is updated according to the following rules:

$$\text{IF } N_1 \neq 0 \text{ THEN } \vec{d}_j(t+1) = -\sum_{i=1}^{N_1} \frac{\vec{r}_{ji}}{\left|\vec{r}_{ji}\right|}. \tag{2}$$

//robot j responds by moving away from the N_1 neighbours of ZOR

ELSE

//robot j does not interact

$$\text{IF } N_2 \neq 0 \text{ THEN } \vec{d}_j(t+1) = \sum_{i=1}^{N_2} \frac{\vec{v}_i}{\left|\vec{v}_i\right|}. \tag{3}$$

//robot j will attempt to align itself with the N_2 neighbors of ZOO

ELSE $\vec{d}_j(t+1) = \vec{d}_j(t)$

//robot j does not interact

End

A noise η effect is modeled by introducing uniformly from the interval $[-\eta/2, \eta/2]$.

The order parameter of the model is described by the average normalized velocity v_a:

$$v_a = \frac{1}{N v_0}\left|\sum_{j=1}^{N} \vec{v}_j\right|. \tag{4}$$

On the other hand, we study the susceptibility. This parameter allows us to calculate the critical values of the interactions. It is defined as a function of the order parameter v_a and the number of robot N:

$$\chi = N^2[\langle v_a^2\rangle - \langle v_a\rangle^2] \tag{5}$$

Simulation Results and Discussion

With the progress of technology, especially in artificial intelligence, we see now the robots collaborate with humans and, in some cases, are able to work independently. In our modelling and simulation we based on quantitative methods by used the mathematical analysis and the statistical method to describe, explain and predict the dynamic and complex phenomena through operational concepts in the form of measurable variables (like collective motion of robot in the field of logistics). We start, by the representation of the motion of storage robots (for example the robots used in Amazon warehouses: ROBOT KIVA) in warehouses or dynamic storage centers. So, as you see in the Figure 4 the motion of the robots is almost ordered. For the reason that the values that we took about: noise, radius of repulsion, radius of orientation, density and the initial velocity are practically proportional. But in Figure 5, we can observe that when we increase the noise value

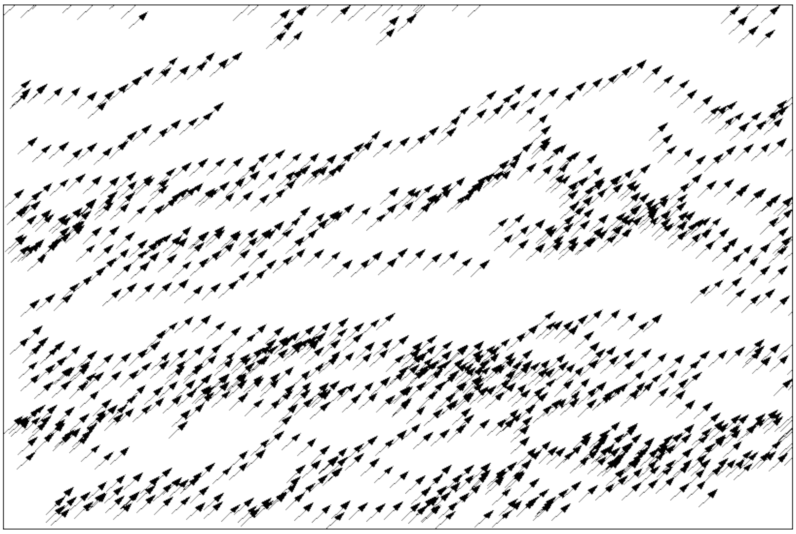

Figure 4: Motion of robot in the warehouses for fixed value of the density ρ=2.0, noise η=2.0, R_1=0.1, R_2=1.0.

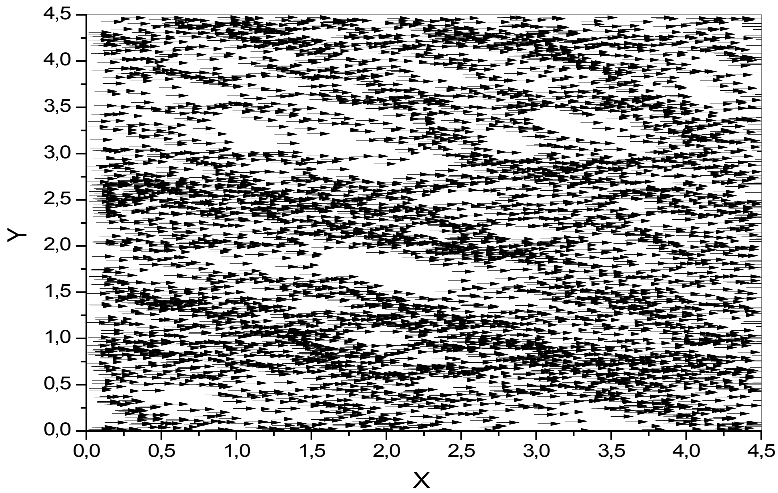

Figure 5: Variation of the position (X,Y) of robot for fixed value of the density *ρ=2.0, noise η=4.0, R_1=0.6, R_2=1.0.*

or the radius of repulsion the movement of robot in storage centers is completely disordered. From these two figures we can understand that the phase transition and the motion of robot in warehouses depend on the size of our system, the value of radius of repulsion and noise. Consequently, if we project the results of our simulation in the warehouse, we find the same constraint of motion.

In Figure 6 we give an illustration of the variation of the average velocity ν_a as a function of R_1 for different values of noise η [10-19]. In the case of no noise η=0, we observe a sharp decreasing of velocity ν_a with R_1. Also when we increase the noise η we remark that the velocity decreases rapidly, and becomes equal to zero ν_a=0. And the transition regime will be done. So to determine the critical value of radius of repulsion R_1, and know from at what value of R_1 the velocity become equal zero, we call the parameter of susceptibility χ. In Figure 7, we describe the variation of susceptibility χ as function of radius of repulsion R_1 each pic of χ gives us the critical value of radius of repulsion R_{1c} for fixed value of noise and density [number of robots N divided by the surface S(ρ= N/S)]. In Figure 8 we determine the critical radius of repulsion R_{1c} as a function of noise for different values of the density ρ. We observe for fixed value of noise the radius of repulsion R_{1c} increases much more one increases the density, and we show also that the radius of repulsion R_{1c} decreases rapidly when the noise increases. Logistically speaking, if we project our interpretation on the motion of robots in storage centers, we find that, when the velocity decreases, the time also decreases. This is projected on the delivery of the commodity to the customers. Our control parameters must be taken to manage the robots in storage centers. And our result prove that how the big company; can be enter to manage the world value chain, that's what we call the strategic management.

In Figure 9, we analyze the variation of the velocity versus the radius of orientation R_2 with different values of the noise η [10-19]. For a fixed density, the figure shows that the velocity ν_a increases with the radius of orientation R_2 in the regime of low noises and this increasing becomes more rapidly as well as the values of noise decrease.

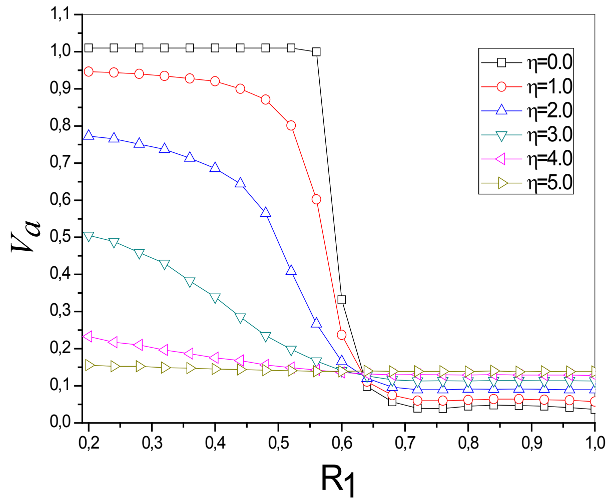

Figure 6: Variation of the average velocity v_a as a function of R_1 for different values of noise η and for fixed value of the density ρ=2.0.

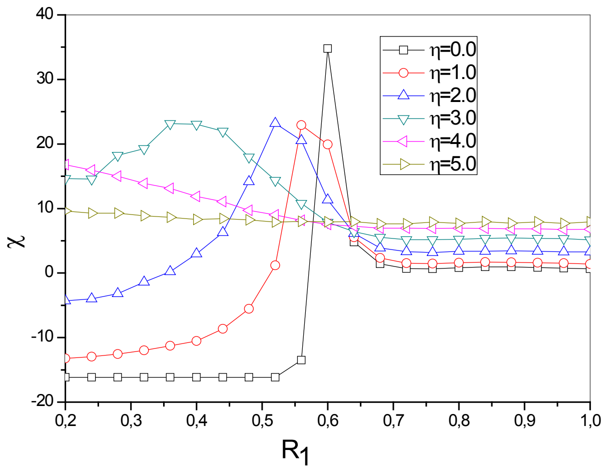

Figure 7: The susceptibility χ as a function of radius of repulsion R_1 for different values of the noise η.

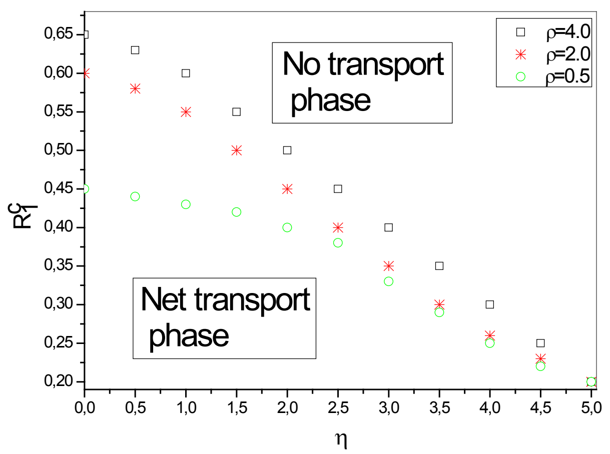

Figure 8: The critical radius of repulsion R_{1c} as a function of noise η for different values of the density ρ.

This phenomenon can be logistically interpreted as follows: when the size of orientation zone R_2 is large, the robot has a great probability to align itself with the neighbours. As a result, the robots move coherently in the same direction in this limit of low noises. In addition, while in the regime of high noises, the average velocity v_a becomes practically independent on the orientation radius R_2. In consequence, the value R^*_2 can be interpreted as a critical value. It separates the ordered state in which the robot move cooperatively in the same direction and the disordered state in which the robot move without help in random direction. Thereafter, the Figure 10, allows us to determine the critical value of radius of orientation R_{2C}. In other words, we plot in Figure 11 the variation of R_{2C} as a function of noise η. We observe for different values of the density ρ the critical value of radius of orientation R_{2C} increase rapidly, and when we increase the density for fixed noise the critical value of radius of orientation R_{2C} decreases. We can project our interpretation on storage center management: from our results, when we increase the noise and the zone of repulsion we find the zone of orientation become less important. The motion of robot in warehouse becomes disordered and the time needed to deliver the command

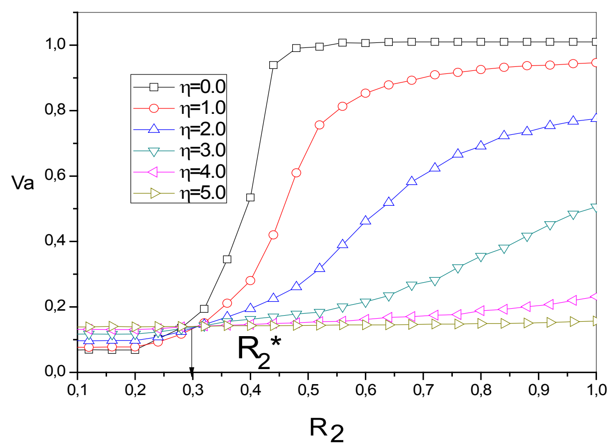

Figure 9: Variation of the average velocity v_a as a function of radius of orientation R_2 for different values of noise η for fixed value of R_1=0.1 and ρ=2.0.

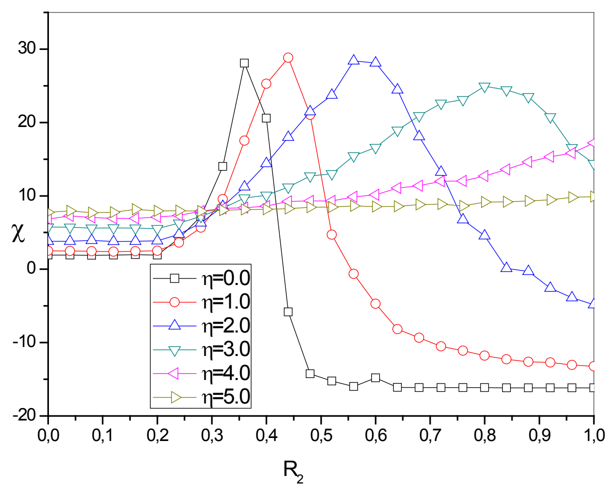

Figure 10: The susceptibility χ as a function of radius of orientation R_2 for different values of the noise η.

becomes huge, and this problem is projected on our insertion in the global value chain.

As a final point, we are discussing the effect of the size of the repulsion zone on the ordering of robot during their motion in the warehouse. As can be seen from the Figure 12, the increasing of the size of the repulsion zone in our model has the effect of making little sharply the transition between ordered and disordered states and to change the values of R^*_2 at which this transition occurs. More generally, the critical value of R^*_2 increased linearly with the radius of repulsion zone R_1. Consequently, the variation of $\ln(R^*_2)$ as a function of radius of repulsion $\ln(R_1)$ it is in exponential form. Hence, we can write this variation as form of scaling function $R_2^*=R_1^K$, with K describes the critical exponent $K=1.03 \pm 0.07$. This function allows us to understand the relation between R_2 and R_1. In conclusion, the robot in warehouse or storage center must be programmed by taking the adequate value, as like as: R_2, R_1, η and ρ, in the interest to have a fast motion v_a, which is projected on the global value chain, and all that allows us to always keep customers and increase the turnover of company.

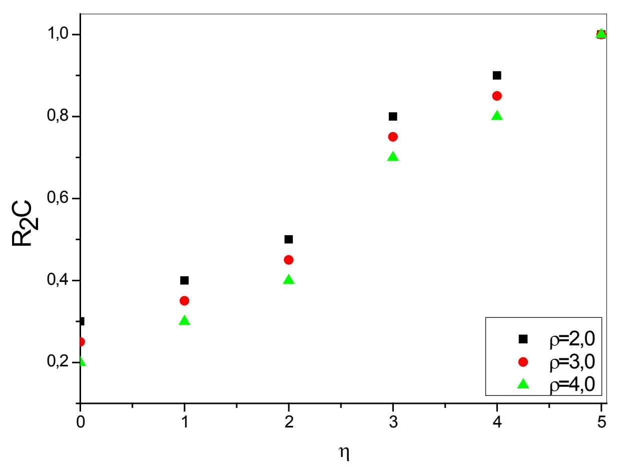

Figure 11: The critical radius of orientation R_{2c} as a function of noise η for different values of the density ρ.

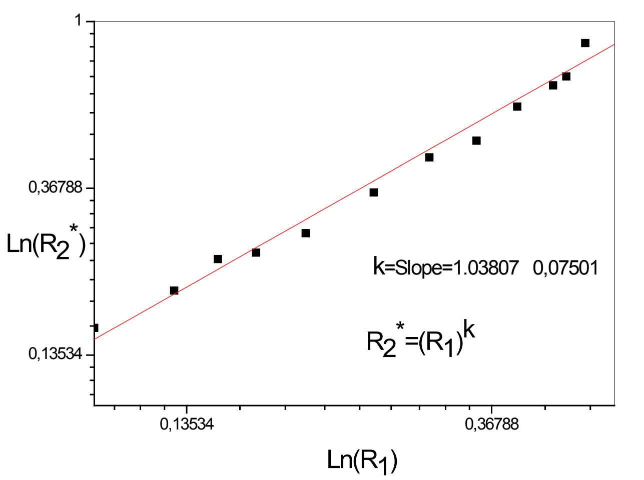

Figure 12: Variation of critical radius of orientation R^*_2 as a function of radius of repulsion R_1.

Conclusion

In our investigation of the study the collective motion of robots in supply chain, we have understood that the radius of orientation and the repulsion plays a very important role to optimize the delivery time of the command in the warehouse. The increasing or decreasing the velocity as function of noise for different value of radius of orientation or repulsion, it is automatically projected to the required time of delivery. In addition, the motion of robot is done by the noise, this parameter also is important, because, the decreasing of the noise value allowed us to increase the velocity of our system. Also, in our paper we take by consideration the critical value of radius of repulsion and the critical value of radius of orientation. These parameters allow us to separate the regime that the robots move in a disordered or orderly way. In other words, the density in our study describe the number of robot divided by the surface, this parameter influences our system to evolve with time. In addition, we have concluded our result by putting the relation between the radius of repulsion and the radius of orientation. This equation describes a scaling function with critical exponent. So from our model and our numerical simulation we understand why the big companies of e-commerce invested much more in the intelligence logistic, because, in interest to have a supply chain equipped with a system of information in the form of robots. The importance of these robots in warehouses is to increase the velocity of delivery and to minimize the time of delivery of command to customers.

For instance, Morocco has adopted an integration strategy in the global value chain; this took the form of a national pact for industrial emergence; in order to attract new international investments in different sectors such as the automobile; aeronautics. The insertion of the robots in the Moroccan logistic platforms will make it possible to optimize the delivery time of the orders, to increase the turnover of companies and impact positively the gross domestic product of country.

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