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A numerical procedure for evaluating physical parameters of ergonomic assessment for cart pushing/pulling tasks

A. Greco[a]*, R. Sepe[b], F. Caputo[a]

[a]*Department of Engineering, University of Campania Luigi Vanvitelli, via Roma 29, Aversa, Italy*
[b] *Department of Chemical, Materials and Industrial Production Engineering, University of Naples Federico II, Piazzale V. Tecchio 80, Neaples, Italy*

Abstract

Manual Material Handling (MMH), by pushing or pulling carts, is a common task that characterizes any manufacturing or service operation, and there is always a significant human input to those operations in terms of physical load.

The physical load represents the effect of input forces during MMH operations that depend on the interaction between material handling equipment and the working environment.

Many times MMH represents a critical issue related to human-machine interaction due to the carts can work in environment with parameters different from those used in designing, subjecting workers to risk of musculoskeletal disorders.

The aim of this work, developed in collaboration with Fiat Chrysler Automobiles (FCA), is to develop a new procedure that allows estimating the initial and the maintenance forces necessary to push or pull carts, knowing the characteristics of the cart and the environment in which it works, in order to preventively assess the ergonomic indexes according to ISO 11228-2.

The procedure is based on multibody simulations. The cart is modeled by Computer Aided Design (CAD) code and, then, imported in a multibody code where numerical simulations are performed in order to calculate the forces. In the multibody code static and dynamic friction coefficients of bearing of wheels are assigned, together with parameters of contact between wheels and floor. Changing the pivot angle of two floating wheels, several simulations have been carried out.

Moreover, considering a cart used at the assembly line of the FCA plant of Pomigliano d'Arco (Naples), experimental tests have been performed in order to validate the procedure by comparing numerical results with the experimental ones.

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* Corresponding author. Tel.: +39 0815010318.
E-mail address: alessandro.greco@unicampania.it

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1. Introduction

Despite the massive automation and mechanization, the manual handling of materials is still a considerable part of the industrial working activities.

In general, manual material handling (MMH) means that components can be lifted, carried, pushed or pulled by the workers' upper limbs, as said by Snook et al. (1978). There are several risk factors associated to MMH activities, principally evaluated from four perspectives: epidemiology, psychophysics, physiology and biomechanics. Hoozemans et al. (1998) reviewed the literature about the risk factors for musculoskeletal disorders related to pushing and pulling that are associated with low back pain. Other risks are caused by join moments at the shoulder during the operating task. Purposely, Chow and Dickerson (2016) provided guidelines to aid design of pushing/pulling tasks in the context of shoulder physical capacity.

Designing a manufacturing working environment is a very complex process, in which a large amount of variables (technological, environmental, ergonomic) needs to be taken into account. Nevertheless, current manufacturing processes design procedure do not consider all of these variables. In particular, ergonomic aspects are often neglected during the design phase.

Moreover, about the pushing/pulling activities, often, because of technological reasons or lack of availability on the market, companies are forced to design and realize homemade carts, even without a proper expertise.

Computer-Aided Engineering (CAE) clearly offers new possibility to integrate ergonomic knowledge into the design process. A wide variety of ergonomic topics are of relevance to the application of numerical models for the evaluation of the ergonomic parameters since and during the design phase, as already demonstrated by Caputo et al. (2018), Matebu and Dagnew (2014), Spada et al (2016).

According to ISO 12228-2, the ergonomic assessment for manual handling by means of pushing/pulling actions is based on the evaluation of the initial force (IF) and the maintenance (or sustaining) force (MF) necessary to move the carts.

For achieving this goal during the design phase, the use of multibody models can help the engineers in designing the carts taking into account the ergonomic aspects. Multibody analysis allows investigating the kinematic and dynamic behaviors of a mechanical assembly.

Multibody modeling and analysis are widely used in several engineering field of application (mechanics, aeronautics, biomechanics, etc.).

This paper is aimed to propose a numerical procedure, based on multibody analysis, which allows creating and simulating the motion of a cart in a digital environment, in order to analyze the kinematics and the dynamics of the system since and during the design phase. This procedure is coherent with the Digital Manufacturing (DM) strategy, based on Virtual Testing of the design solutions.

Simulating the system behavior under operating conditions into the work environment, before its physically building, allows the designer to minimize design errors and the economic risks they pose.

The following is a description of the procedure used to determine the forces required to push/pull carts using the Adams code by MSC®.

In order to prove the reliability of the procedure, data from simulation have been compared with those obtained by an experimental session in the Fiat Chrysler Automobile (FCA) plant of Pomigliano d'Arco (Naples), regarding the data acquisition about pushing/pulling of a cart used for material manual handling in the assembly line.

In addition, an ergonomic evaluation, according to the procedure suggested by standard ISO 11228-2, is described, by comparing experimental and numerical results.

2. Test Article and Experimental Tests

The cart for handling some structural components of the Fiat Panda has been investigated (Fig. 1).

Fig. 1. Investigated cart.

The cart has a mass of 70 kg and, in full-load condition, it can carry 72 components, each with a mass of 4.6 kg. In the in-service condition, the total handled mass (cart plus components) is practically 400 kg.

The cart is characterized by two floating wheels and two fixed wheels.

The experimental tests have been performed in order to evaluate the initial and the maintenance forces necessary for the occupational injury risk index evaluation by applying the method proposed by Snook and Ciriello (1991).

The procedure has been performed according to ISO 11228-2.

The experimental tests, for both pushing and pulling actions, have been carried out under this condition: push/pull the cart in order to cover 1 m distance in at least 10 s, starting from a velocity equal to 0 m/s and reaching a velocity of 0.1 m/s after 10 s.

The number of tests for each evaluated action, according to ISO 11228-2 and to the FCA guidelines, are reported as following:

Initial forces evaluation:

- 15 tests for pushing actions with the starting wheels' orientation of 90°, with respect to motion direction;
- 15 tests for pulling actions with the starting wheels' orientation of 90°, with respect to motion direction;
- 15 tests for pushing actions with the starting wheels' orientation of 0°, along the motion direction;
- 15 tests for pulling actions with the starting wheels' orientation of 0°, along the motion direction;

Maintenance forces evaluation:

- 30 tests for pushing actions;
- 30 tests for pulling actions.

During the tests, the IF and MF are measured by means of a dynamometer, placed on the handhold. The considered IF corresponds to the maximum acquired value, while the considered MF corresponds to the average of the values acquired after 10 s from the starting of the test.

In this case, the distance covered during the test is of 5 m and the point of application of force (handhold) is 100 cm high with respect to the floor.

Now, it is necessary evaluate the difference, in percentage, between the maximum and minimum acquired values of forces, according to equation (1):

$$\Delta E = \left[\left(F_{\max} - F_{\min} \right) / \left(\frac{F_{\max} + F_{\min}}{2} \right) \right] x100 \tag{1}$$

$$\Delta E \leq 15\% \tag{2}$$

If the equation (2) is satisfied, it is possible to consider the maximum evaluated values. Otherwise, iteratively, the maximum and minimum values have to be removed from the list, until the equation (2) is satisfied.

Table 1 and Table 2 show the experimental values of Initial and Maintenance Forces respectively. In both tables, the couple of maximum and minimum values that satisfy the equation (2) are highlighted.

Table 1. Experimental values of Initial Force

TEST	PUSHING FORCE [N]		PULLING FORCE [N]	
	Initial Force (wheels at 90°)	Initial Force (wheels at 0°)	Initial Force (wheels at 90°)	Initial Force (wheels at 0°)
1	147	70	130	70
2	**143**	79	138	80
3	136	76	132	79
4	134	85	134	80
5	127	85	**129**	85
6	145	88	**145**	**88**
7	140	90	145	90
8	149	80	149	80
9	130	**75**	130	**75**
10	**125**	82	138	82
11	118	**87**	148	80
12	140	75	140	85
13	132	79	132	88
14	125	87	125	87
15	125	80	125	80
Max	**143**	**87**	**145**	**88**

By applying the equation (1) and satisfying the equation (2), the IF and MF have been evaluated.
About the initial force the values are:

- Pushing action with starting wheels orientation of 90°: $IF_{push90°} = 143$ N;
- Pulling action with starting wheels orientation of 90°: $IF_{pull90°} = 145$ N;
- Pushing action with starting wheels orientation of 0°: $IF_{push0°} = 87$ N;
- Pulling action with starting wheels orientation of 0°: $IF_{pull0°} = 88$ N;

Table 2. Experimental values of Maintenance Force

TEST	MANTEINANCE FORCE [N]	
	PUSHING	PULLING
1	44	43
2	**46**	50
3	42	41
4	42	49
5	46	46
6	45	45
7	50	50
8	55	55
9	44	44
10	43	43
11	55	55
12	54	54
13	51	51
14	56	56
15	44	44
16	56	56
17	54	55
18	50	50
19	54	54
20	55	55
21	60	55
22	50	50
23	**53**	53
24	50	50
25	55	45
26	52	**52**
27	52	42
28	41	41
29	52	52
30	49	**49**
Max	**53**	**52**

About the maintenance forces the values are:

- Pushing action: $MF_{push} = 53$ N;
- Pulling action: $MF_{pull} = 52$ N.

3. Multi-body model

The CAD model of the investigated cart has been realized, consisting in the chassis, the base and the four wheels, two fixed and two floating, composed each one by two steel disks (Fig. 2).

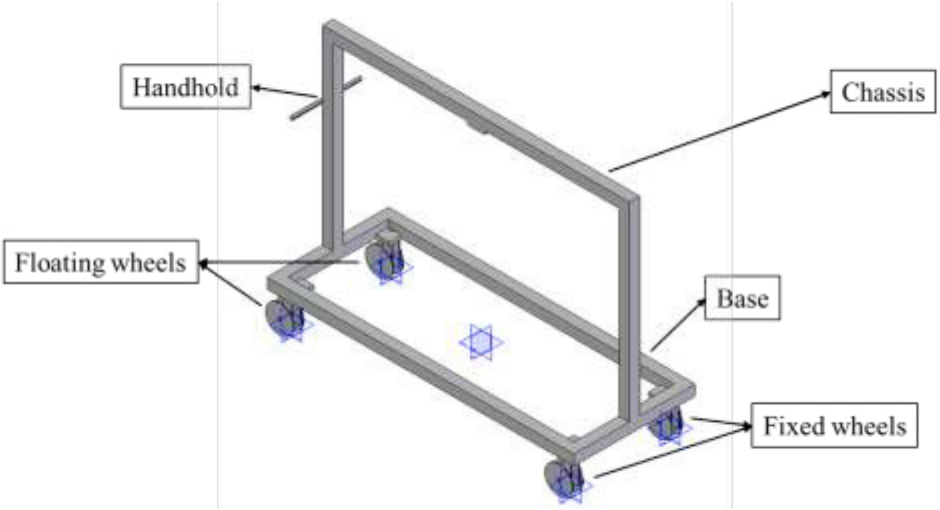


Fig. 2. CAD model of the cart.

The payload has been considered by modeling a concentrated mass located at the center of the chassis.

In addition, the floor has been modelled with elastic and damped characteristics.

The several parts of the structural components (chassis, base, and handhold) have been modelled as rigid bodies, connected to each other by means of rigid constraints.

Subsequently, by assigning the material density, the inertias of the structure have been evaluated. In addition, the constraints between parts, the friction coefficients between parts (wheels, pivot) and the friction coefficients between wheels and floor have been defined.

The multi-body model has been imported in Adams® code for numerical simulations (Fig. 3).

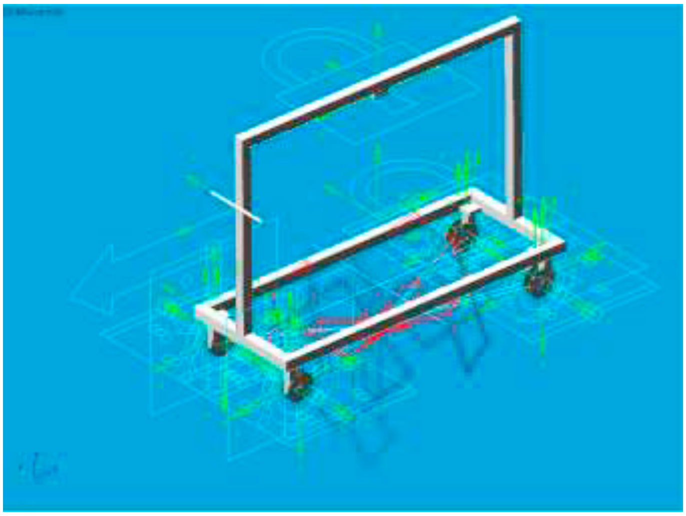


Fig. 3. Multi-body model in Adams software environment.

3.1. Constraints application

The constraints between the chassis and the wheels have been applied, realizing a kinematic chain.

The constraints have been defined as following:

- Base – wheel pivot;

- Wheel pivot – wheel;
- Wheel – floor.

The connection between the base and wheel pivot has been realized by means of a revolute joint, in order to allow the pivot rotating perpendicularly with respect to the plane during the cart motion (Fig. 4.a).

Similarly, the connection between wheels and pivots has been realized by means of a revolute joint (Fig.4.b).

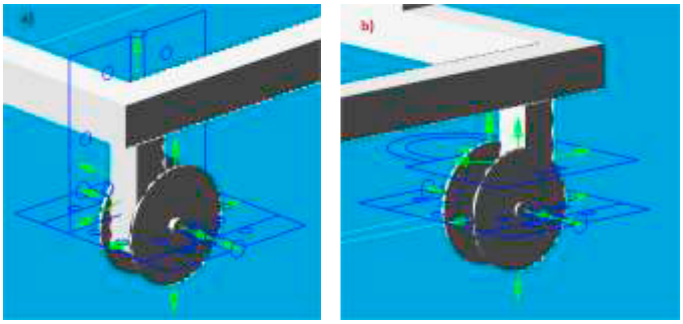


Fig. 4. (a) Revolute joints for floating wheels; (b) Revolute joints for fixed wheels.

The stiffness, damping and friction properties, along and around the three axes, have been provided by FCA and they are strictly reserved.

Finally, the floor, made of rubber, has been modeled as a solid and positioned in such a way as to be tangent to the wheels.

In order to take into account elastic-kinematic characteristics of contact between the floor and the wheels, a contact constraint was defined between each wheel and the floor.

The friction coefficients, provided by the FCA, are described in Table 3 and Table 4.

Table 3. Joints friction coefficients.

Joint	Radius [mm]	Static friction coefficient	Dynamic friction coefficient
Revolute joint chassis – pivot	20	0.02	0.011
Revolute joint pivot – wheel	20	0.02	0.011

Table 4. Contact friction coefficients.

Contact	Wheel Radius [mm]	Static friction coefficient	Dynamic friction coefficient
Contact wheel – floor	80	0.5	0.1

The simulations have been performed considering a duration of 15 *s* with a time step equal to 0.06 *s*.

4. Results Analysis

The simulation has been performed by defining a motion translation, according to the standard. The velocity starts from 0 mm/sec and reaches the value of 100 mm/sec after 10 sec, as shown in Fig. 5, for both pushing and pulling cases.

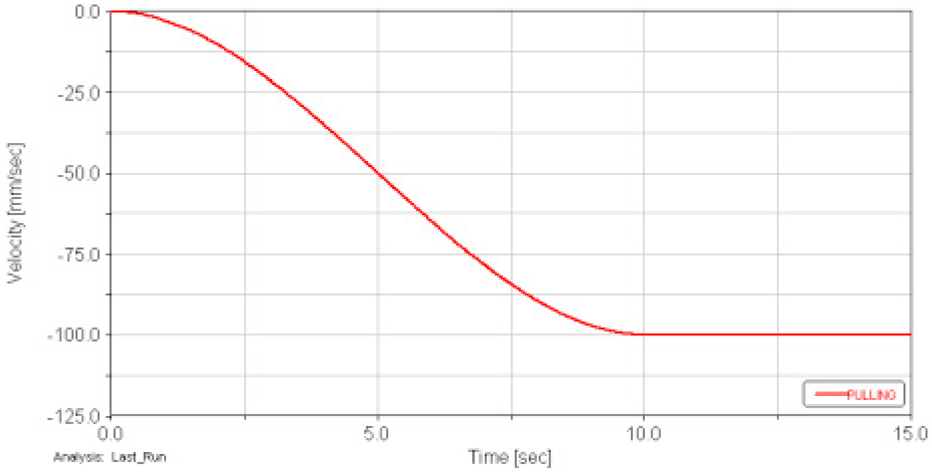


Fig. 5. Velocity low for pulling.

Fig. 6 and 7 show the trends of forces required to pull and push the cart, respectively, with the starting wheels orientation at 0 deg with respect to the motion direction. For both pushing and pulling forces, the trends reach almost the same absolute values.

The initial force is related to the maximum value of the trend, while about the maintenance force, the average value after 10 sec has been considered.

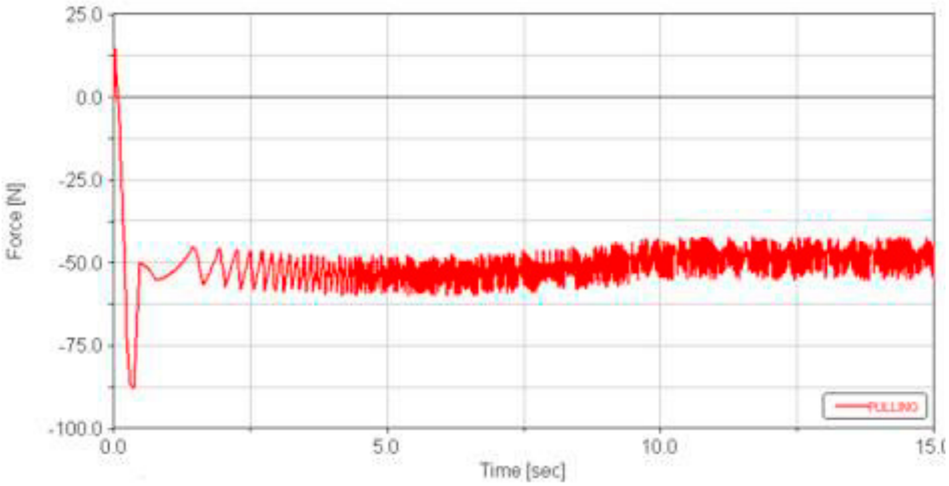


Fig. 6. Force trend for Pulling, starting wheels orientation of 0°.

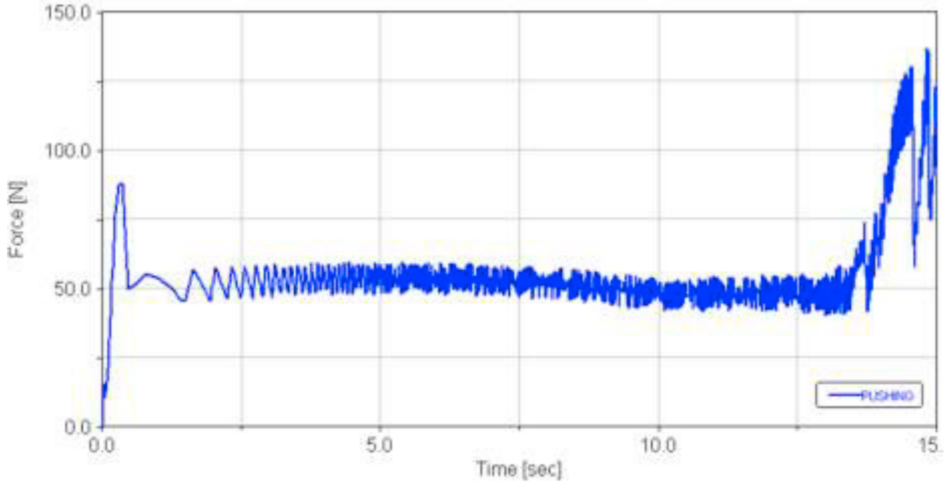


Fig. 7. Force trend in Pushing, starting wheels orientation of 0°.

Fig. 8 shows the trends of the rotation angles around the vertical pivots of the floating wheels during the motion for pulling action. The pivots are free to rotate around their own axis during the motion and this motivates the presence of slight oscillations in their trends. The oscillations of the rotation angles, in turn, cause the oscillations in the forces trends of Fig. 6 and 7, during the maintenance phases. The trends of rotation angles around the vertical pivots are practically the same also for pushing action.

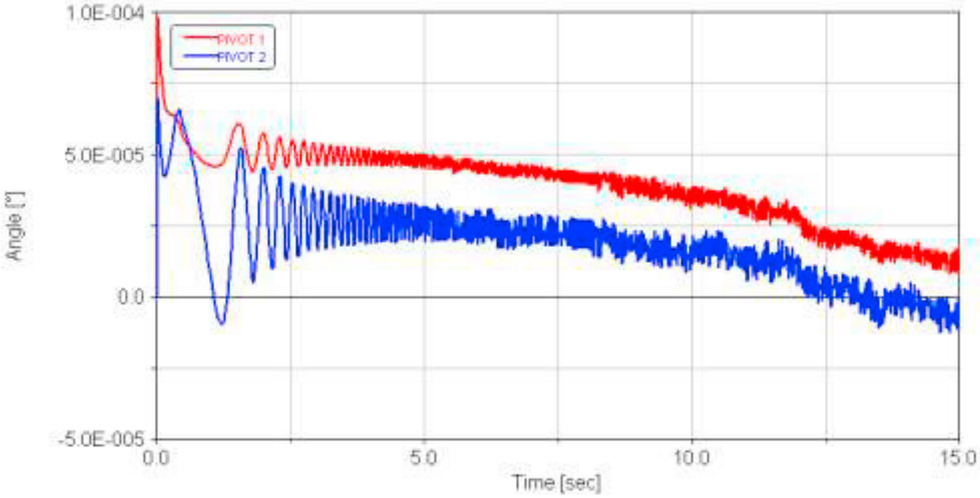


Fig. 8. Rotation angles around vertical pivot for the floating wheels, with starting orientation of 0°.

Fig. 9 and 10 show the trends of forces required to pull and push the cart, respectively, with the starting wheels orientation at 90 deg with respect to the motion direction. The wheels rotate around the vertical axis until they are aligned with the motion direction.

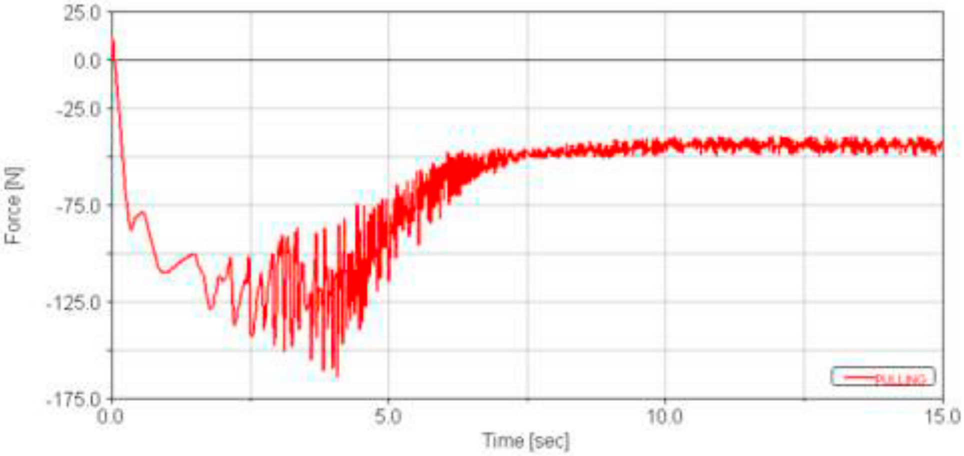


Fig. 9. Force trend for Pulling, starting wheels orientation of 90°.

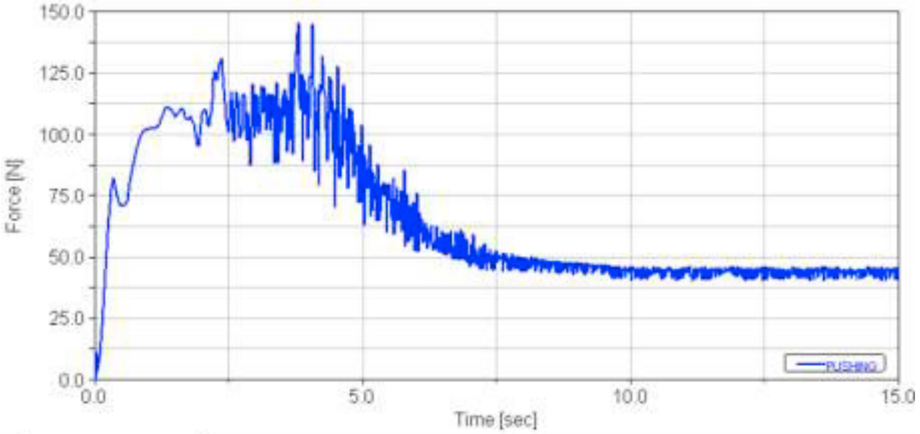


Fig. 10. Force trend in Pushing, starting wheels orientation of 90°.

Fig. 11 shows the trends of the rotation angles around the vertical pivots of the floating wheels during the motion for pulling action. In this case, there is the presence of slight oscillations in their trends also, that cause the oscillations in the forces trends of Fig. 8 and 9, during the maintenance phases. The trends of rotation angles around the vertical pivots are practically the same also for pushing action.

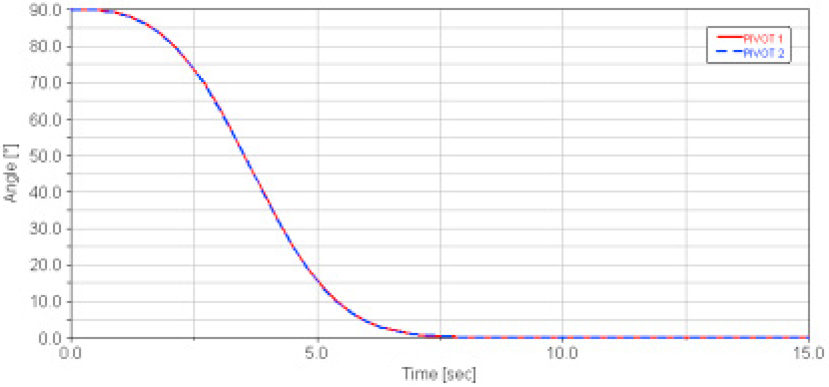


Fig. 11. Rotation angles around vertical pivot for the floating wheels, with starting orientation of 90°.

Table 5 and Table 6 show comparison between the experimental and numerical results for pushing and pulling tests respectively. It is worth to note that the considered maintenance forces, in the following tables, are those one acquired during the experimental tests with the wheels starting orientation at 0°.

Table 5. PUSHING: numerical – experimental results comparison.

Floating wheels starting condition	Initial Force – IF			Maintenance Force – MF		
	Experimental	Numerical	Difference	Experimental	Numerical	Difference
0 *deg*	87 N	87.97 N	3 %	53 N	51.5 N	2.8 %
90 *deg*	143 N	144.5 N	1 %	-	-	-

Table 6. PULLING: numerical – experimental results comparison.

Floating wheels starting condition	Initial Force – IF			Maintenance Force – MF		
	Experimental	Numerical	Difference	Experimental	Numerical	Difference
0 *deg*	88 N	87.95 N	0.05 %	52 N	49.75 N	4.3 %
90 *deg*	145 N	150.5	3.8 %	-	-	-

From the results, it is possible to say that numerical results are in good agreement with the experimental ones, with an error lower than 5 %.

5. Ergonomic risk evaluation

The risk evaluation for pushing/pulling activities is performed by applying the Snook and Ciriello (1991) procedure. It is based on the so-called "Psychophysical Tables", which provide important information on the capabilities and safe limit loads of manual load handling operations. These tables describe the recommended limit values for Pushing/Pulling actions, showing the maximum initial (IF) and the maximum maintenance (MF) forces recommended for the healthy adult working population as a function of: sex, displacement distance, frequency of actions and height of hands from the ground.

The risk index RI is evaluated by the following equation (3):

$$RI = \frac{W_T}{W_R} \tag{3}$$

where W_T is the transported weight and W_R is the recommended weight.

The recommended limits, in terms of maximum initial (IF) and maximum maintenance (MF) forces are determined from the table for *maximum acceptable force of push/pull for male/female*.

FCA has provided the geometrical (covered distance) and physical (frequency) data that characterize the working activity. In particular, the considered covered distance is of 5 m, while the frequency is one handling each 33 *min*.

By using the Psychophysical Tables of Snook and Ciriello (1991), the recommended values, suitably linearly interpolated, for maximum initial and maintenance forces are shown in Table 7.

The values consider a handhold height of 100 cm and they pertain to the 90% of the industrial population.

Table 7. Recommended weight.

RECOMMENDED WEIGHT [N] (height: 100 cm; distance: 5 m; frequency: 1 action/33 min; 90% of population)				
	PUSHING		PULLING	
Gender	IF	MF	IF	MF
MALE	256.3	165.3	242.2	170.6
FEMALE	195.2	97.7	204	107.7

Table 8 and Table 9 show the Risk Indexes for pushing and pulling activities, according to equation (3), based on numerical and experimental data. The considered IF values are those one related to the starting wheels orientation of 90 deg with respect to the motion direction.

Table 8. Risk Index for PUSHING.

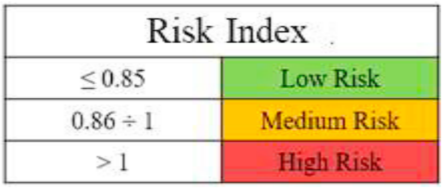
Gender	PUSHING: RI for IF			PUSHING: RI for MF		
	Experimental	Numerical	Difference	Experimental	Numerical	Difference
Male	0.558	0.564	1.07 %	0.32	0.311	2.8 %
Female	0.732	0.740	1.09 %	0.54	0.527	2.4 %

Table 9. Risk Index for PULLING.

Gender	PULLING: RI for IF			PULLING: RI for MF		
	Experimental	Numerical	Difference	Experimental	Numerical	Difference
Male	0.598	0.621	3.84 %	0.305	0.291	4.6 %
Female	0.710	0.738	3.94 %	0.483	0.462	4.34 %

Also for the RI evaluation, the numerical results are in good agreement with the experimental ones with differences lower than 5 %.

In addition, according to the RI area of Fig.12, it is possible to say that the RI scores are within the Low Risk Area.



Risk Index	
≤ 0.85	Low Risk
0.86 ÷ 1	Medium Risk
> 1	High Risk

Fig. 12. Snook and Ciriello Risk Index areas.

6. Conclusions

A preventive ergonomic evaluation of manual handling activity is a formidable task that allows designing equipment and resources taking into account the ergonomic variables since during the design phase of a production process.

Numerical model can provide many data that can be used for these aims.

This paper proposes a numerical procedure, based on CAD and multibody modeling and analysis, for the evaluation of the forces necessary to assess the ergonomic index related to pushing/pulling tasks according to the Snook and Ciriello procedure.

By comparing the numerical and experimental results it has been proved that the numerical procedure provides results in good agreement with those one provided by the experimental procedure for both forces evaluation and ergonomic scores evaluation.

Concluding, the procedure is reliable and ready to be applied, giving support to engineers and ergonomists during the design of a production process.

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References

Caputo F., Greco A, D'Amato E., Notaro I., Spada S., 2018. A preventive ergonomic approach based on virtual and immersive reality. International Conference AHFE 2017, Advances in Intelligent System and Computing.

Chow A. Y., Dickerson C. R., 2016. Determinants and magnitudes of manual forces strength and joint moments during two-handed standing maximal horizontal pushing and pulling. Ergonomics 59 (4), 534-544.

Hoozemans M.J.M, Van der Beek A.J., Fringsdresen M.H.W., Van Dijk F.J.H., Van der Woude L.H.V., 1998. Pushing and pulling in relation to musculoskeletal disorders: a review of risk factors. Ergonomics 41 (6), 757-781.

ISO 11228 (2003) Ergonomics – Manual Handling, Part 2: pushing and pulling.

Matebu A., Dagnew B., 2014. Design of manual material handling system through computer aided ergonomics: a case study at BDTSC textile firm. International Journal for Quality Research 8 (4), 557-568.

Resnick M., Chaffin D., 1995. An ergonomic evaluation of handle height and load in maximal and submaximal cart pushing. Applied Ergonomics 26 (3), 173-178.

Snook S.H., Campanelli R.A., Hert J.W., 1978. A study for three preventive approaches to low back injury. Journal of Occupational Medicine (20), 478-481.

Snook, S.H., Ciriello, V.M., 1991. The design of manual handling tasks: revised tables of maximum acceptable weights and forces. Ergonomics, 34 (9), 1197-1213.

Spada S., Germanà D., Sessa F., Ghibaudo L., 2016. FCA Ergonomics proactive approach in developing new cars: virtual simulation and physical validation. Advances in Intelligent System and Computing 418, 57-63.