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CADOProSys Software. Design Conveyors and AGVS

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Abstract
CADOProSys Software (Computer Aided Design and Optimisation of Production Systems) was developed by the authors of this paper for didactic purposes, to facilitate the analysis and selection of certain equipment and processes occurring in production systems. Thus, this software can support the didactic process, by introducing IT into the selection and design stage, without eliminating the needs of knowledge of theory, of the design of material handling logistic equipment. The software is developed on several modules, a general one for defining the production system, one for selecting the production system and one for logistics. Within the logistics component, the application has implemented the robotic structure selection module and the material transport equipment selection module, the one presented in this paper. In the context of Industry 4.0, designing and choosing systems geared exclusively to the current needs of the user are essential processes. The application is structured on the theoretical design of the equipment concerned, but also connects to the technical specifications of existing components on the market.

Keywords
conveyor, supply chain, selection

1. Introduction

CADOProSys Software was developed as educational software based on the need of both teachers and undergraduate to obtain production systems designed as accurate as possible. As any educational software, CADOProSys was specifically designed to lead a learner to develop an activity, to execute one. It was designed to satisfy both pedagogical and teaching setting.

The general flowchart of the computer application is shown in Figure 1.

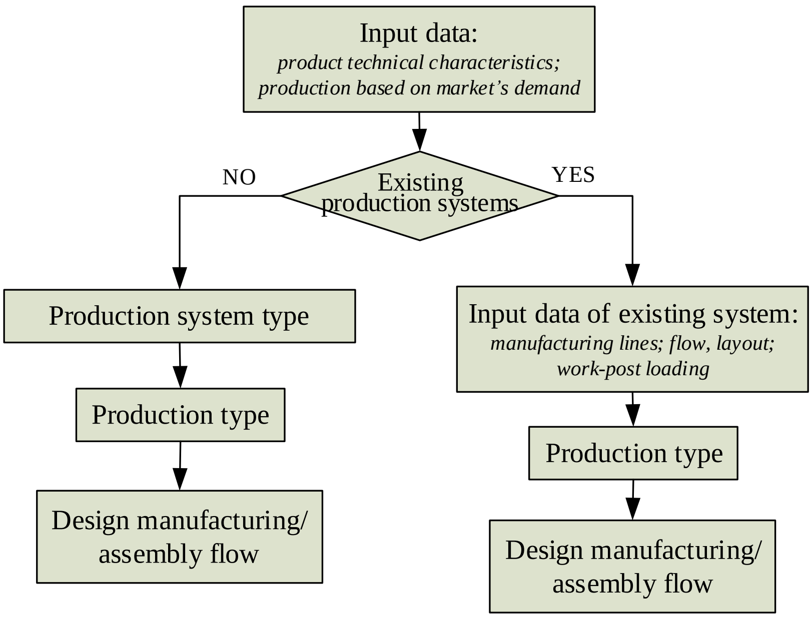


Fig. 1. General flowchart of CADOProSys application

This flowchart was the basis for the development of the design and selection of the production system, respectively of the design and selection of the logistics system (Figure 2). The process selection and general logistics (choice of suppliers) were presented by the authors at international conferences.

This paper is intended for the process of designing the material handling system, with focuses towards conveyors.

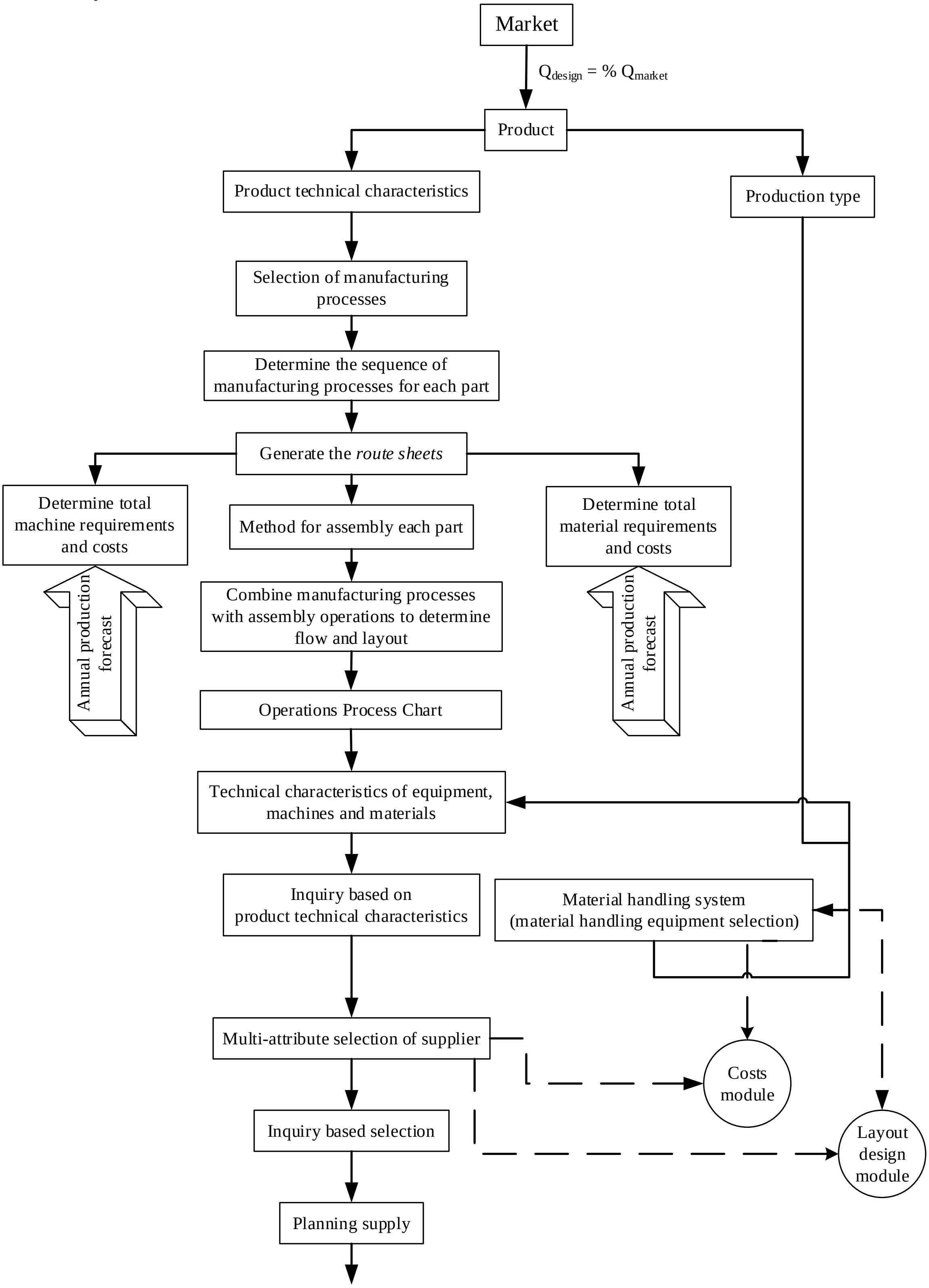


Fig. 2. Flowchart of CADOProSys application

2. Related Works

A conveyor is a mechanical device or assembly that uses flexible traction elements, such as belts, cables, or chains, to transport material with minimal effort. A conveyor can have continuous or intermittent motion, depending on its type and purpose. A conveyor can be used to transport materials during their processing, such as in the food, metallurgical, textile industries, etc. A conveyor can also have a curved shape to adapt to complex routes, both horizontally and vertically. They may be driven by a motor, by gravity, or manually.

In recent years, it has been considered essential to find solutions for transporting liquids and gases, starting from their properties and characteristics. For this reason, it is hardly surprising that recent years have brought to the technical market a lot of literature dealing with the fundamentals of fluid mechanics, fluid flow, hydraulics and related topics. What is surprising, however, especially since one of the most active industries is automotive (solid transport) is that there is not the same development in the field of solids handling. Certainly, the variety of materials being handled in bulk is almost endless, ranging in size from fine dust to rocks, in value from refuse to gold, and in temperature from deep-frozen peas to near-molten metal.

In fact, it is extremely important that the implementation of the transport process was strictly matched with a specific technology [1-3].

There are, in the literature, a number of scientific papers oriented on conveyor design. Thus, there are concerns in designing transport systems from the point of view of energy efficiency [4]. Other studies are focused on designing conveyors by minimizing life cycle costs [5, 6].

The vast majority of literature deals with the design of belt conveyors. Belt conveyors are an effective way of transporting large amounts of material compared to other options. They are essential for the continuous movement of dry bulk material, especially in the mining and coal power sectors. By controlling the speed of the belt conveyors, the energy consumption can be reduced, but the challenge is to deal with the dynamic behaviours of the conveyors and the speed control, which are crucial for the energy efficiency and performance of the system. Therefore, a proper analysis by modelling and simulating the conveyor belt could lead to lower power consumption and operating costs [7].

There are researchers [8] that developed a prototype of a conveyor belt system that can rotate 360 degrees and has a mechanism to lift and lower the material. The mechanism was designed for safety and for sorting the material into the correct compartment. Others design a belt conveyor system with two rollers to carry weight to a certain distance between two shaft axes [9] or a belt conveyor system for limestone using three rolling idlers [10]. They generated design data for industrial use. They considered the size, length, capacity, and speed of the belt, as well as the roller diameter, power, and tension, idler spacing, drive unit type, diameter, location, and arrangement of a pulley, and maximum load capacity. In another research [11] was analysed the design of three roller-type belt conveyor systems for coal handling. They performed a finite element analysis and testing on the pulley and its components under different speeds and loads.

There is even a comparative study, quite extensive, which makes an analysis from the point of view of theoretical and quantitative calculations of Chinese, German and USA design standards of screw conveyors [12]. This study made a comparison between the three standards in terms of standardized values of geometric parameters (screw diameter, screw pitch, screw or conveying distance, flight type) and operational parameters (mass flow, rotational speed, filling degree, power consumption).

On the other side, Automated Guided Vehicle Systems (AGVS) are an important component of intralogistics. The technological standard and the experience with this automation technology that is now available have led to AGVs finding their way into almost all industries and production areas [13].

Over the past seven years, China has incredibly developed its AGVs manufacturing industry, with the number of manufacturers increasing from 10 to over 40. Most equipment has been manufactured based on the technical requirements imposed by the automotive industry, which has an extremely high degree of automation and where the concepts of Industry 4.0 and more recently 5.0 are most often implemented. Thus, the fields in which AGVs have been implemented more and more often are: AGV as a mobile workstation in the pre-assemblies; tractors, piggyback and forklift truck AGVs for assembly belt supply; in the warehouse, for picking and material delivery to the lines; interlinking of production machines in aggregate manufacturing, etc. [13].

There are researchers [14] that argue that driver-less vehicles will play a vital role in the future of manufacturing companies. They claim that human-robot interaction is the most effective way to achieve industrial success from an Industry 4.0 perspective [15]. However, most of the existing literature on AGVs focuses on their technical features and systems (such as guidance systems, routes, sensors, etc.) and neglects other important aspects such as operational factors (such as training hours, pedestrian flow, etc.).

3. Principle of Designing Conveyor

3.1. General aspect in designing conveyors

There are many parameters that influence the design of a conveyor system, such as the type, size, weight, and shape of the material to be conveyed, the speed and capacity of the conveyor, the layout and environment of the facility, the integration with other equipment and systems, and the safety and hygiene requirements. Different types of conveyors have different advantages and disadvantages, depending on the application and the material being transported. Some of the common types of conveyors are belt, roller, chain, bucket, screw, pneumatic, and magnetic.

Thus, it should be started by defining the user requirements of the conveyor(s). What is the main purpose of the conveyor(s): to minimize manual handling, perform a specific process function, such as cooling, or increase the automation of a process, such as rejecting defective products or dividing products into different stations or machines? It should be also considered the level of human interaction needed and the kind of operations that will occur at the conveyor(s), for example flexible packing stations [16].

After determining the purpose of the transport system, it is necessary to understand exactly the type of object to be handled. Defining it implies knowing the size range, speed ranges required by the manufacturing flow, frequency of product feeding, composition, temperature at the entrance and exit of the conveyor, transport mode (bulk, piece by piece), if there is a need to divide / separate / reunite during a transport unit.

Another aspect that significantly influence the design is space constrains: the layout of the flow, the relationships between different equipment, access to existing equipment, number of accessible sides, operation flow on a particular workstation. It is also important to analyse existing equipment, if any, in order to design an integrated system, including SCADA/PLC systems.

The environment plays also an important role for example explosive atmospheres, humidity and temperature conditions. These conditions directly influence the encapsulation of some components, maintenance, cleaning needs (frequency and type). Depending on these possible conditions, collection trays, accessibility on certain parts of the conveyor, removable conveyor elements can be added.

3.2. Study case: design of belt conveyors

The components of a classic belt conveyor are shown in Figure 3.

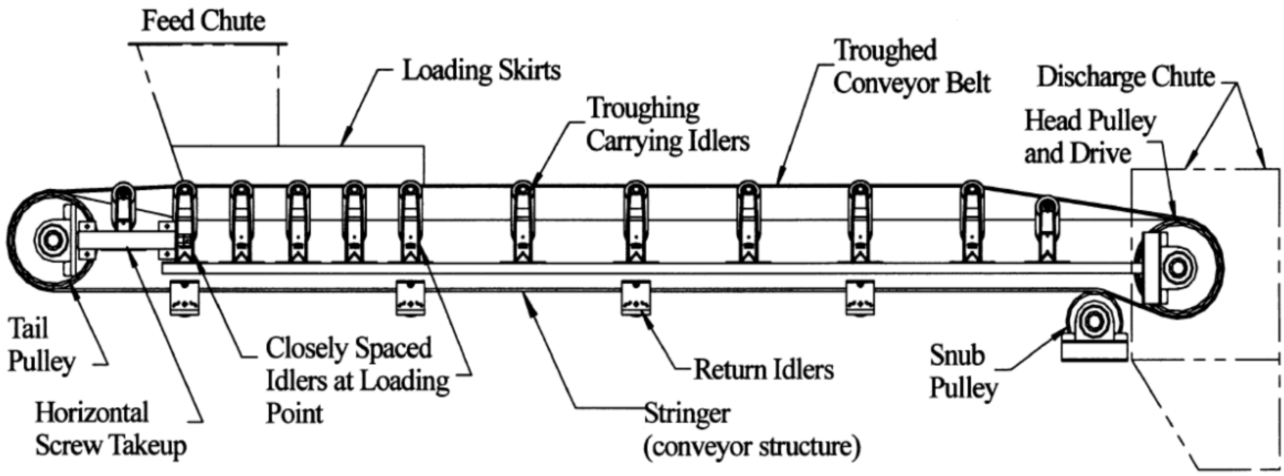


Fig. 3. Component of a belt conveyor [17, 18]

The main component of a typical belt conveyor are as follows:

1. The **belt**, which forms the moving and supporting surface on which the conveyed material is placed. The belt not only carries the material, but also transmits the pull. It is the tractive element.
2. The **idlers/rollers**, which form the support for the troughed carrying strand of the belt and the flat return strand.
3. The **pulleys**, which support and direct the belt and control its tensions.
4. The **drive**, which imparts power through one or more pulleys to move the belt and its load. Usually, the drive is an electric motor with reduction gears.
5. The **structure**, which supports and maintains the alignment of idlers, pulleys and drive.

Designing of a belt conveyor means choosing and determining specific characteristics for each component listed above.

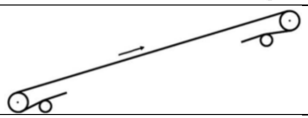
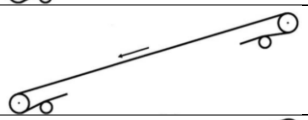
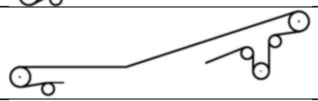
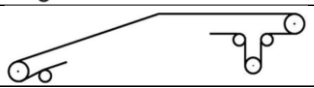
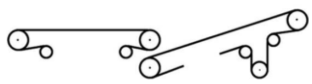
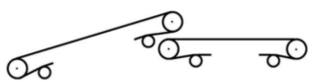
The tension in the belt on the two sides of the drive pulley is not the same in any belt drive. The tension on the carrying run, where the drive pulley is the discharge pulley, is higher and is called the tight side tension (T_1). The tension on the return run is lower and is called the slack side tension (T_2). The slack side tension is necessary to drive the belt. The difference between the tight side and slack side tensions is called the effective tension (T_E). This is the tension that does the work. The effective tension required at the drive pulley to move or hold back the loaded conveyor at the design speed of the belt v, in m/min, determines the horsepower (HP) needed at the drive of a belt conveyor [16]:

$$HP = T_E \cdot v \tag{1}$$

The power required to drive the belt is a function of effective tension produced by the resistance forces. The resistance force is determined by: friction in idlers bearings and seals, conveyor belt displacement, material displacement on the belt, inertia and friction generated by the acceleration of the transported part from the loading area, friction with side walls of chutes in the loading area, etc. In addition, the force required for the drive depends on the trajectory, the type of engine arrangement, tape material.

In designing the conveyor, the travel paths of parts should be determined. From this point of view there are several variants, as can be seen in Tabel 1.

Table 1. Conveyor travel paths [17]

Type of paths	Significance
	horizontal conveyor – both directions transportation
	incline or uphill conveyor where the material is transported to a higher elevation from lower elevation
	decline or downhill conveyor where the material is transported to a lower elevation from higher elevation
	horizontal conveyor followed by ascending path (used when space will permit vertical curve and belt strength will permit one belt)
	ascending followed by horizontal path conveyor (used similar to the above one)
	horizontal followed by ascending pathways with two conveyors (needs additional wear on the belts at the feeding points, dust raised and possible plugging in the transfer chutes)
	ascending followed by horizontal pathways with two conveyors (needs additional wear on the belts at the feeding points, dust raised and possible plugging in the transfer chutes)
	combination path that can be used on a single, long, overland conveyor

The formula for pulling force F_p [N], depends on the path and the constructive mode of the conveyor. Thus:

- horizontal conveyor

with return drums and support drums:

$$F_p = \mu_R \cdot g \cdot (m + m_B + m_R) \tag{2}$$

with return drums and table support:

$$F_p = \mu_T \cdot g \cdot \left(m + \frac{m_B}{2}\right) + \mu_R \cdot g \cdot \left(\frac{m_B}{2} + m_R\right) \tag{3}$$

- uphill conveyor

with return drums and support drums:

$$F_p = \mu_R \cdot g \cdot (m + m_B + m_R) + g \cdot m \cdot \sin \propto \tag{4}$$

with return idlers and table support:

$$F_p = \mu_T \cdot g \cdot \left(m + \frac{m_B}{2}\right) + \mu_R \cdot g \cdot \left(\frac{m_B}{2} + m_R\right) + g \cdot m \cdot \sin \propto \tag{5}$$

- downhill conveyor

with return drums and support drums:

$$F_p = \mu_R \cdot g \cdot (m + m_B + m_R) - g \cdot m \cdot \sin \propto \tag{6}$$

with return drums and table support:

$$F_p = \mu_T \cdot g \cdot \left(m + \frac{m_B}{2}\right) + \mu_R \cdot g \cdot \left(\frac{m_B}{2} + m_R\right) - g \cdot m \cdot \sin \propto \tag{7}$$

where: μ_R - friction coefficient when running over roller; μ_T - friction coefficient when running over table support; m - mass of the goods conveyed over the entire length conveyed (total load); m_B – mass of belt (total mass); m_R - mass of all rotating drums, except for drive drum; α - machine's angle of inclination.

The friction coefficients implemented are those usual for materials used for conveyor belt [19] (Table 2).

Table 2. Friction coefficient [19]

Coefficient	**0, A0, E0, T, U0, P**	**NOVO**	**U1, V1, VH**	**UH, V2H, U2H, V5H, V10H**	**TXO**
μ_T (table)	0.33	0.33	0.5	0.5	0.18
μ_T (galvanised slider beds)	-	-	-		0.24
μ_R (roller)	0.033	0.033	0.033	0.033	-

Furthermore, in designing the belt conveyor there were considered: elongation head drives; mechanical capacity, typical efficiency of a belt conveyor, steady state shaft load.

The purpose of these calculations was to determine the required actuating force based on the product being transported and the speed imposed. This force allows selection of drive type and validation of conveyor dimensions based on resistance calculations.

4. CADOProSys – Conveyor Design

4.1. Application flowchart

The conveyor design component of CADOProSys assumes that the user knows what type of conveyor is suitable for his production/assembly line.

The design of conveyors starts from selecting the type of conveyor, identifying the components of each type of conveyor and then activating the calculation area specific to the selected type. The flowchart of the application is shown in Figure 4. The user must select different values for different conveyor components. The values used in the software are the usual ones found in existing systems on the market. The user can also enter their own value. The software, at the present stage, makes the calculations but does not validate the results by resistance calculations.

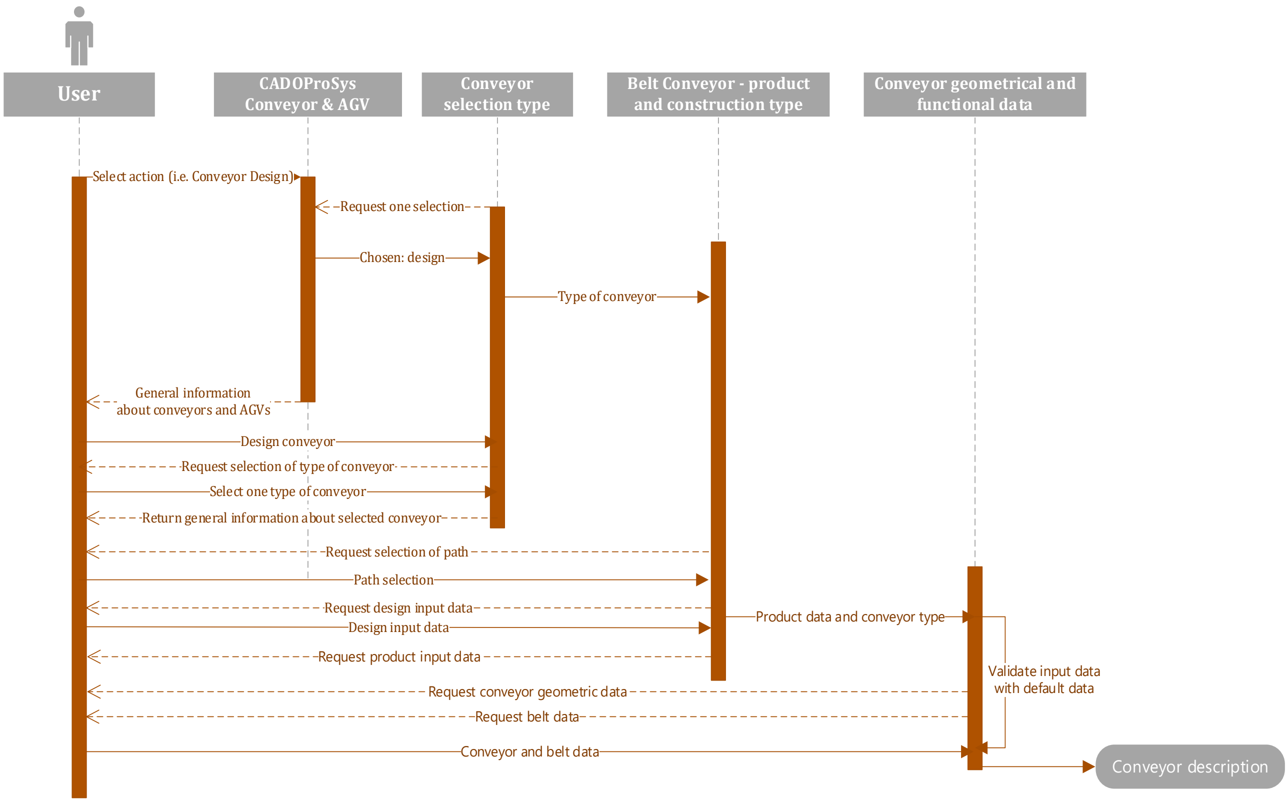
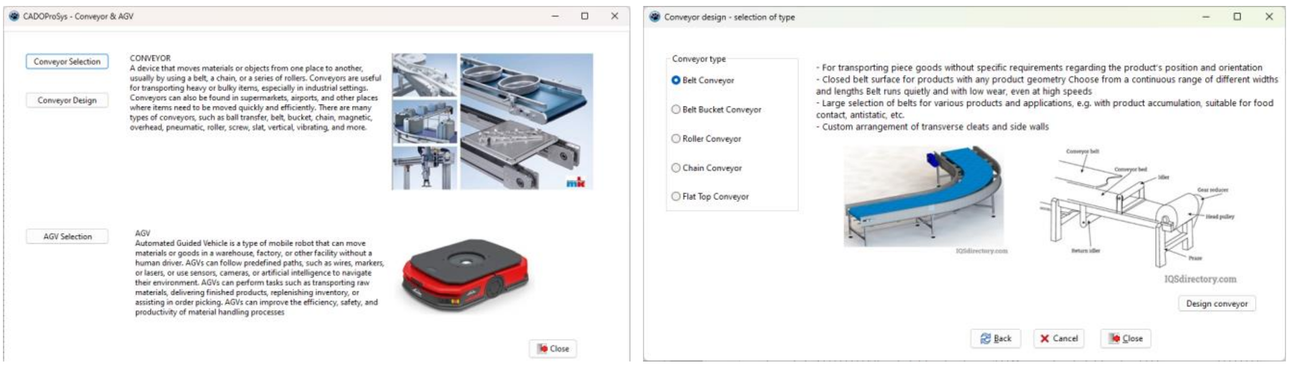


Fig. 4. Flowchart of CADOProSys – Conveyor Design

4.2. Application interface - Conveyor design

The interface is a cascade windows one, the user can return to the previous step at any time and make changes (Figure 5).



a) b)

Fig. 5. Interface of CADOProSys – Conveyor Design

The application also provides a series of general information related to conveyors, respectively AGVs on the main page (Figure 5a), and then, after selecting a type of conveyor, data related to the functionality of the selected type is received, an image with an example of a conveyor and its components (Figure 5b).

For belt conveyors, the application includes the two variants of transported product: bulk and piece-by-piece. For each of them must be entered some data that will be used in determining the characteristics of the conveyor. If, for example, the user chooses to transport individual parts using a conveyor sled, all options related to bulk materials become inactive (Figure 6). Also, for the selection of band tension there are explanations that allow the user to see what material will be used for the tape.

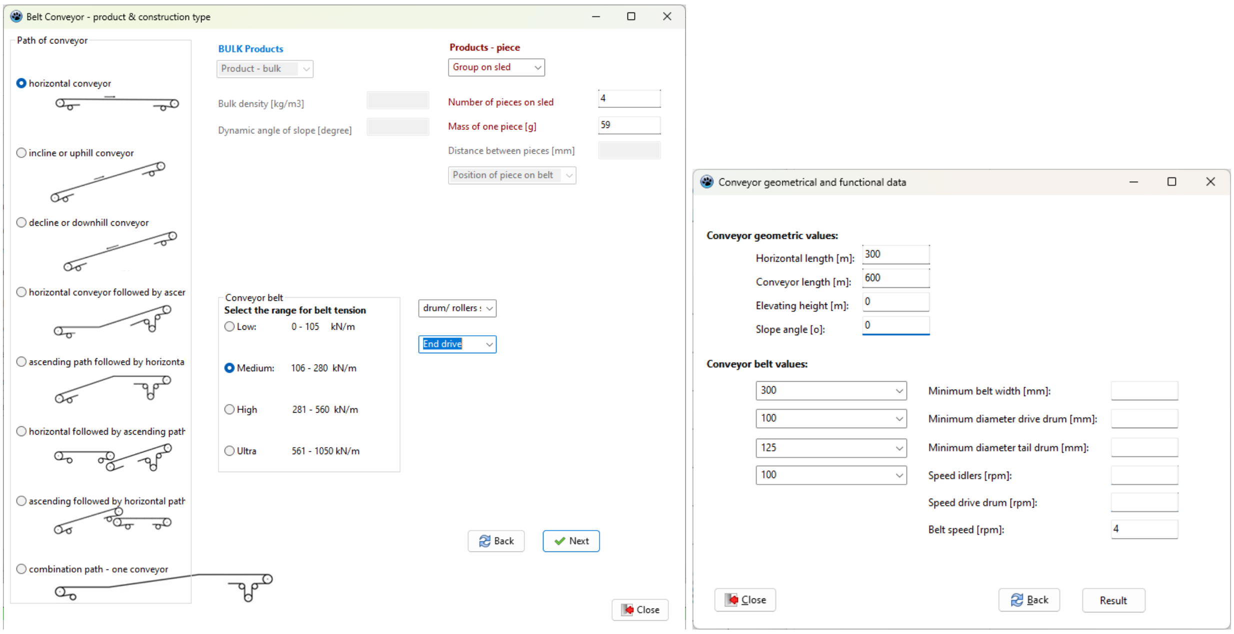


Fig. 6. Interface of CADOProSys – Conveyor Design (Product& conveyor data)

3. Conclusion and future work

After all the data is entered, the application calculates the required force and checks whether the system is functional. If the results obtained from the calculations fall within the specific parameters, then a list of specifications appears (extracts the data entered by the user and adds the calculated data).

If the entered data does not satisfy the functionality conditions, the application generates a message offering a suggestion for resolution (Figure 7).

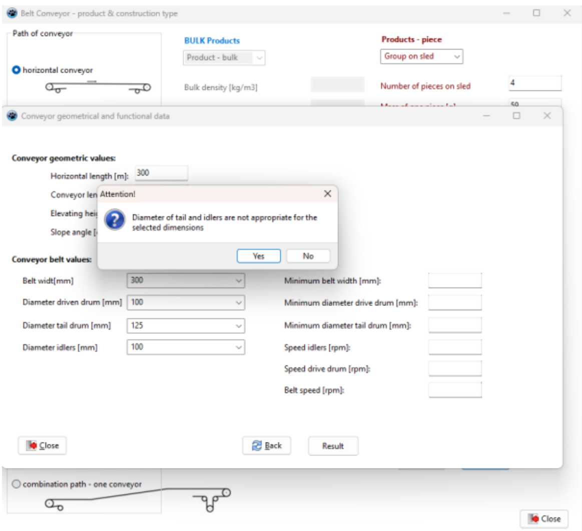


Fig. 7. Results of designing with CADOProSys – Conveyor Design (Product& conveyor data)

CADOProSys – Conveyor Design offers the user the possibility to validate the material transport system based on the design data of the production system. The advantage is that it validates the introduced dimensions, the required speeds and determines whether the solution designed by the designer is valid. With the data obtained, the designer can access the websites of manufacturing companies to purchase a standard product or to order a customized product.

The current version of the application must be developed so that when entering data, their verification is done in real time, so that incompatibility errors (as that from Fig. 7) are eliminated during data entry.

In addition, the application must be developed in the direction of selecting the optimal material transport system, depending on the parameters of the production system. The authors are developing this component of the application, the selection of the optimal trying to be achieved by several methods, including the fuzzy one.

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