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In
ADVANCED CONTROL SYSTEMS M

ANALYSIS AND DYNAMIC MODELING OF INTERMEDIATE DISTRIBUTORS FOR BALANCING OF PRODUCTION LINES

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Chapter 1

Introduction

1.1 The company (PULSAR ENGINEERING SRL)

About the company

Established in 1989, Pulsar is specialized in engineering and manufacturing of solutions for products handling and conveying. Over the years, the company has focused its activities on the Tissue industry, developing special machines and special automatic units. The Group is chaired by Massimo Franzaroli and employees 50 people, located between the Italian production site and the commercial subsidiaries in the United States and China.

The Group's sales network is widespread in about 10 countries worldwide and it is distributed between sales agents and representative offices.

The Group holds over 89 patents and patent pending in the world. In recent years, the Group has launched many innovative solutions dedicated to the Tissue industry.

Group structure

Pulsar is organized as a Group, with various companies, each one with a specific role.

Pulsar Srl is the Mother Company in charge of assets management and of the strategic guidance of the operating companies.

Pulsar Engineering Srl, located in Castel Maggiore (BO), Italy, is the company in charge of marketing, sales and production activities.

Pulsar America Inc., located in Green Bay (WI), is responsible for sales and marketing activities and services to customers in the North American market.

Pulsar Group in the World

The Group consists of a manufacturing plant located in Italy, in Castel Maggiore (Bologna) in the European Packaging Valley, a sales office located in China, Shanghai and in the USA, in Green Bay (WI) in the main North-American Tissue district. Pulsar has also a widespread and consolidated commercial network that covers a large part of the EU territory, Latin and Central America, South Africa, China, Korea and Japan.

Activities

Pulsar is an integrated-approach company, offering services ranging from the layout and production plant engineering to the supply of complete plants. In its operational structure and products, Pulsar joins together engineering and process knowhow dedicated to the TISSUE industry thus becoming a partner in the analysis and identification of the best solution for its customers' systems.

The range of services offered by Pulsar begins from support activities of the complete plant development and productions lines layout, possible thanks to the experience gained in hundreds of realizations around the world and the use of calculation platforms, check and simulation processes, such as TISSUE PLS, software able to simulate production processes, to plan the production lines footprint and to virtually examine the related criticalities.

The relationship with the customer is based on integration and cooperation, in order to achieve excellence and create value for the entire chain.

In addition, Pulsar can offer solutions realized on modular bases, using customized and mainly patented materials, with certified production processes, achieving efficient systems with a guarantee of up to 5 years against wearing.

In recent years, Pulsar has developed sophisticated tools for lines management, such as the REDS supervising software family, which include the HARMONIZER and the REDS PLATINUM platforms. In particular, the PLATINUM software allows to measure the line efficiency with the collection of the operating data and the monitoring of the entire production line, identifying activities to improve it.

Finally, Pulsar can offer the “Quatis systems” for in-line compliance inspection of wrapped and unwrapped products, allowing in this way to qualify the production and certify the production batches quality.

Quatis inspection machines and the Platinum system are unique systems that offer the possibility to define connections between the products quality, the working conditions and the events generated by a line, enabling future improvements.

All Pulsar’s recent innovations are in line with the digitalization of production activities and IoT, with the aim of making production systems more and more efficient and reducing waste of material, time and energy.

1.2 Main Objectives of the Thesis

As introduced before, the main activity in Pulsar is the production of handling systems for products that must be packaged in the tissue sector. This work allows interested companies to optimize internal production thanks to the analyses and tools supplied.

Optimizing a packaging line requires considering many important aspects:

- spaces must be used to best effect;
- machine performance must be maximized;
- the following must be minimized:
  - stand-by times for machines and other equipment;
  - product storage spaces;
  - construction and maintenance costs.
- intervention on damaged parts must be facilitated;
- production must be possible, at least in part, in the presence of damaged machines.

These requirements are possible thanks to the use of specific equipment that allows the flow of products to be sorted on different machines, simultaneously or alternately.

Sorting is created both by simple mechanisms and by real machines.

Sorting strategies, spaces, times, dimensions and costs must be analysed.

The work carried out at the company Pulsar Engineering s.r.l, and discussed in this thesis, focuses on the construction of a model for the dynamic simulation of the operations of a machine that allows feeding and sorting/merging in the tissue sector called **REDS INTERMEDIATE.**

The goal is to derive a powerful dynamic model that can simulate a large range of REDS intermediate that could work in different operating modes (DIVERTER, COMBINER and By-pass modes) and containing all existing operating strategies (REVOLVER and TETRIS strategies). This was possible with the aid of a powerful simulation tool called **PLS DYNAMIC/ TISSUEPLS DYNAMIC.**

It is important to emphasize that we will deal with a simplified production line since we are interested in just getting the REDS INTERMEDIATE model.

This model can be used to:

- Obtain a real estimate of the parameters necessary for the design of a production line.
- See the behaviour of the PULSAR line in a 2D and 3D interface proposed by the software.

The following discussion reports the study in question starting from a general description of the production lines, and a static analysis of the REDS INTERMEDIATE.

Figure 1.1 REDS intermediate

Chapter 2

Characteristics and general operations of Pulsar Lines

In order to highlight the role of REDS INTERMEDIATE, this section deals with the general operating logic of Pulsar production lines, describing the main machines of which it is composed and how they interact with each other.

2.1 General description of a production lines

The Pulsar company mainly produces handling and transport systems for products in the tissue sector. These systems connect the various process machines that make up the production line, with innovative and appropriate solutions for each plant.

A line can usually be divided into two blocks:

- a “production block” composed of: REWINDER, LOG ACCUMULATOR and LOGSAW machines.
- a “packaging line block” composed of different types of packaging machines depending on whether you want to produce bags, packages or boxes. It includes: WRAPPER, BUNDLER, PALLETIZING ROBOT.

All these machines must be connected to each other via product handling systems. And it often happens that they must work with different numbers of conveyors from one machine to another. So, to this list of machines, must be added specialized machines for sorting called REDS (Roll Exchange Divider Systems).

An example of a production line can be observed in Figure 2.1, but there may be many different combinations of lines depending on production needs.

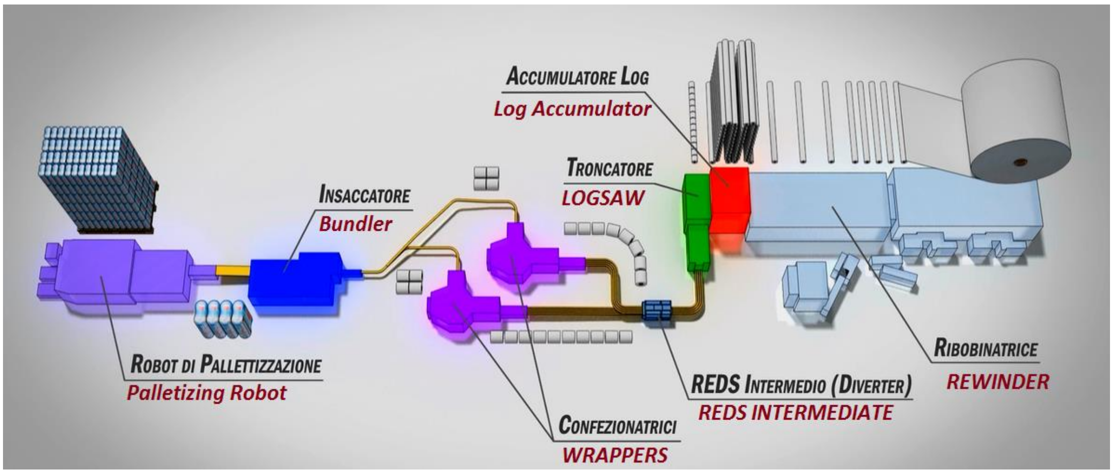


Figure 2.2: Example of production line.

2.2 Machines involved in a production line

Transport lines have different configurations and layouts based on the type of machines they need to connect, the speeds with which they must operate and the type of products to be created. The most common situation in a converting line for tissue is the one in which all the machines are manufactured by different companies, with different speeds and availability. For this reason, we must always know which machinery we are dealing with, their technical specifications and the customer's needs.

2.2.1 Rewinder

The rewinder is the heart of the processing line and we would like it to be the production "bottleneck". It is therefore the slowest machine on the production line, and it should not stop for any reason. The rewinder aims to create the so-called LOGs, starting from a cardboard tube of length between 1600 and 3400 mm, around which the paper is rolled up. A rewinder is part of the "production block". An example of a rewinder and LOGs can be seen in figure 2.2.

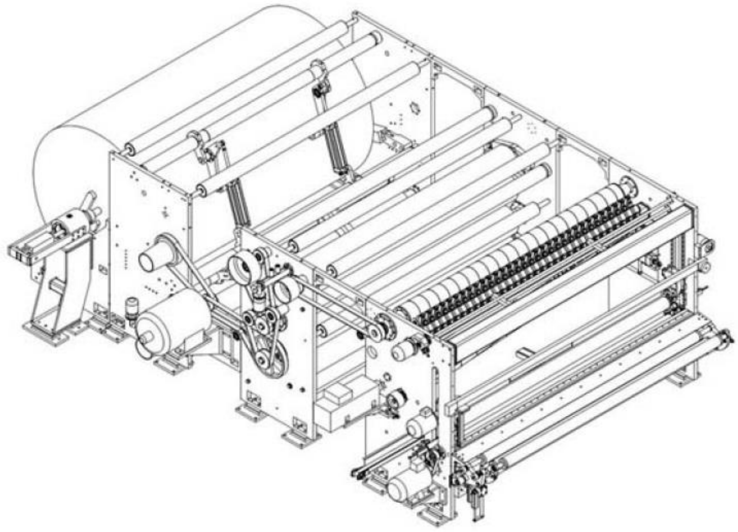


Figure 3.2: Rewinder

2.2.2 Log Accumulator

A log accumulator is a buffer magazine positioned at the exit of the rewinder machine to accumulate the logs. It allows the logsaw machine to be fed as much as possible if the rewinder is not producing, and vice versa it maintains the production of the rewinder in case of temporary failure of the logsaw machine.

2.2.3 LOGSAW

A LOGSAW machine is a cut-off device that, thanks to the use of a blade, cuts the logs into paper rolls of the chosen length and sends them to the subsequent packaging stations. This machine is often connected downstream of the rewinder in a single machine block. It is so obvious that a LOGSAW machine is part of the "production block". Hence, for the purposes of the simulations that will be carried out in this paper, Rewinder and LOGSAW machines will be considered as a single product generation group. Downstream of a cut-off device, can be connected according to the configuration a "LOGSAW REDS", a "REDS intermediate" or a packaging machine. In Figure 2.3, an example of a LOGSAW machine is represented.

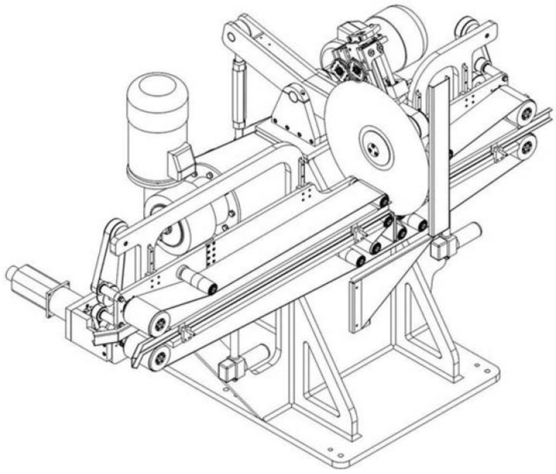


Figure 2.3: Logsaw machine

2.2.4 Wrapper

A Wrapper is a machine that picks up the paper rolls from the conveyors, groups them according to the type of final product to be obtained and wraps them in a flat film that is unrolled from a reel. To take products, it uses pushers that require a minimum of accumulation (queue) at the inlet. This means that the products are not spaced, that the same amount of product can always be taken, and that there is also a minimum of pressure on the products to be launched. A wrapper machine is part of the "packaging line block". An example of this machine can be seen in Figure 2.4.

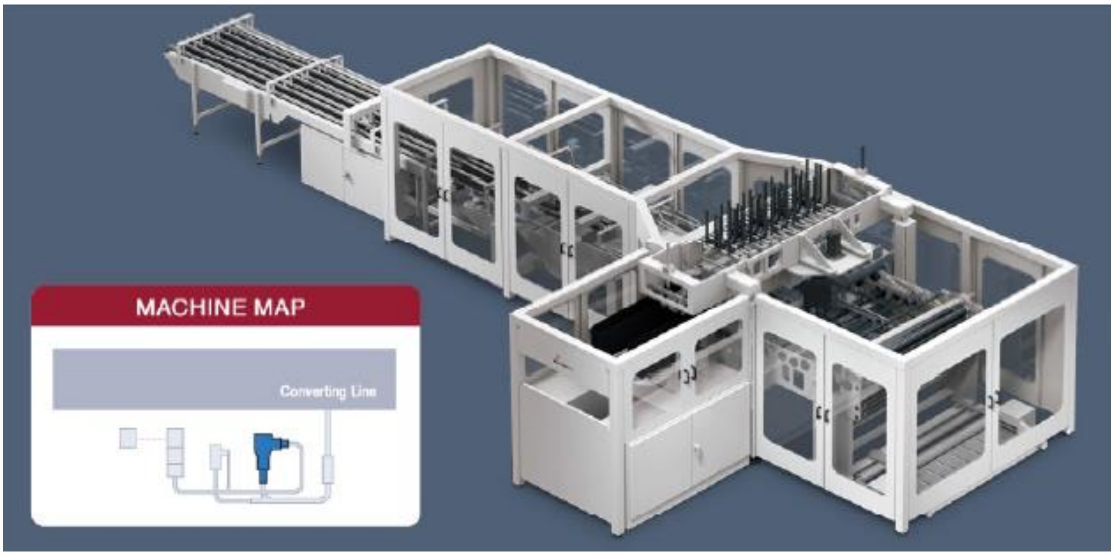


Figure 2.4: Wrapper

2.2.5 Bundler

A Bundler is a machine placed in general downstream of a Wrapper machine in a transport line. They have the function of package a certain number of products, creating packages that contain several small packages. It is part of the “packaging line block”.

2.2.6 Palletizing Robot

A palletizing robot (figure 2.5) is a machine generally placed at the end of a converting line and which allows to place the packages on pallets, thus creating the conditions for transport.

Figure 2.5: Palletizing Robot

2.2.7 REDS (Roll Exchange Divider Systems)

A REDS is a Pulsar patented sorting/merging system that receives a certain number of input channels, which carry the products, and a different number of output channels, from which the products exit. It has an internal mechanical arm that connects these two parts. The inner arm is the only moving part, so the heart of the operation. These machines are also called Diverter or Combiner. There exist two variants depending on how they are placed on the transport line:

- LOGSAW REDS (figure 2.6): It is a sorting/merging machine directly connected to the Logsaw machine. Allows to distribute the flow of cut paper rolls, coming out from the logsaw machine, on different transport channels. The space between the logs, necessary to change the position of the moving conveyors, is created by the logsaw itself to allow the change of the log under the cutting unit.
- REDS Intermediate (figure 2.7): The REDS intermediate, unlike the LOGSAW REDS, is located at a certain distance from the machines to be connected. The products initially grouped in log, are distributed along the path between the exit of the logsaw machine and the REDS intermediate.

Note that the machines upstream and downstream of a REDS intermediate can be any of the machines shown above.

The REDS intermediate is the machine of interest in this work and will be subject of more detailed studies in the following chapters.

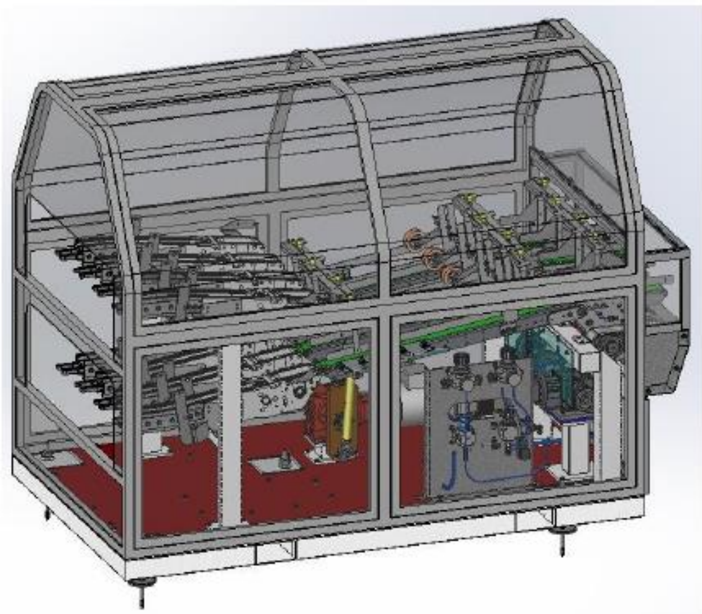


Figure 2.6: LOGSAW REDS

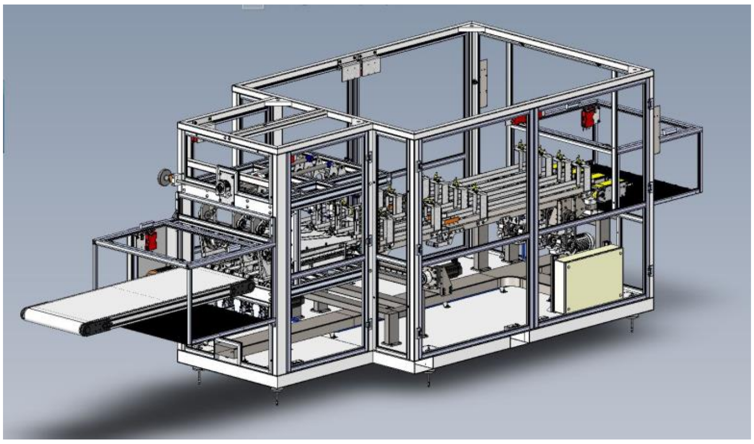


Figure 2.7: Horizontal REDS intermediate

Chapter 3

Static analysis of REDS INTERMEDIATE

3.1 Description

A REDS intermediate (figures 3.1 and 3.2) is a sorting/merging system, located at a certain distance from the machines to be connected, that receives a certain number of input channels, which carry the products, and a different number of output channels, from which the products exit. It has an internal mechanical arm that connects these two parts. The aim of a REDS intermediate is mainly to rebalance the products on a different arrangement between the upstream and downstream of the sorter, since the number of incoming channels is different from the outgoing one. These machines are also called Diverter or Combiner.

Figure 3.1: Vertical REDS intermediate

Figure 3.2: Horizontal REDS intermediate

The mechanical structure of a REDS intermediate may include:

- From 1 to 3 levels of incoming belt conveyors;
- From 1 to 3 levels of output belt conveyors;
- From 1 to 5 belt conveyors per level.

Therefore, it is possible that the sorters manage products that come from several belt conveyors ranging from 1 to 15, to be sorted on an equally variable number of outputs. The possible combinations between incoming and outgoing belt conveyors can thus reach a very high number. However, it would be difficult to balance the sorting and mechanically manage some configurations. Thus, we only work with a limited number of possibilities.

An example criterion is to keep an equal number of channels in all levels when more than one level exists. The possible structures with these assumptions are therefore:

- A level with 1, 2, 3, 4 or 5 conveyors;

- Two levels with 1 + 1 = 2, 2 + 2 = 4, 3 + 3 = 6, 4 + 4 = 8, 5 + 5 = 10 conveyors;
- Three levels with 1 + 1 + 1 = 3, 2 + 2 + 2 = 6, 3 + 3 + 3 = 9, 4 + 4 + 4 = 12, 5 + 5 + 5 = 15 belt conveyors;

So, a real sorter must work with one of the 210 possible configurations.

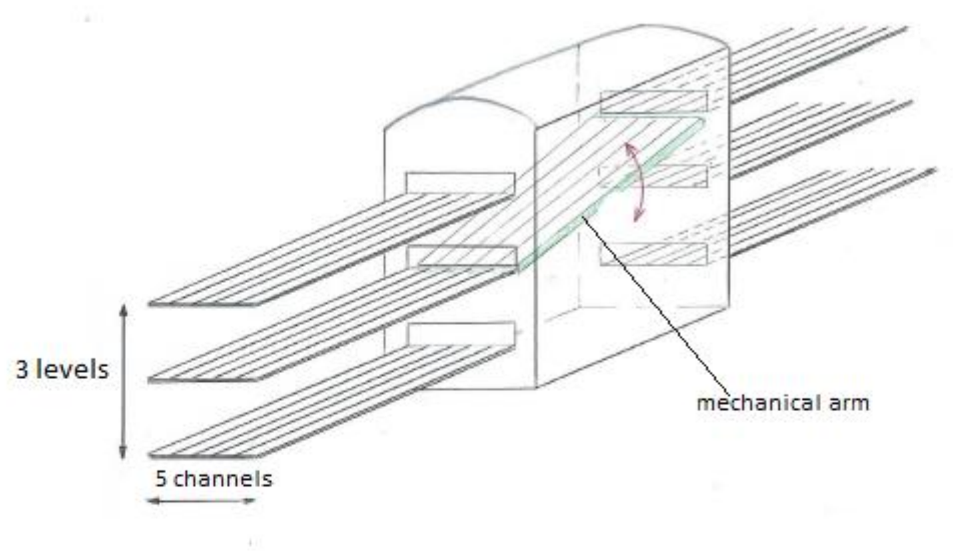


Figure 3.3: diagram of a REDS intermediate

3.2 Location of a REDS INTERMEDIATE on a production line

As we said before, an intermediate sorter is a machine inserted between two or more packaging machines to balance product flows.

To work in a good way, it needs a certain amount of product upstream, and consequently a relative space to receive it. It also needs a free downstream space where

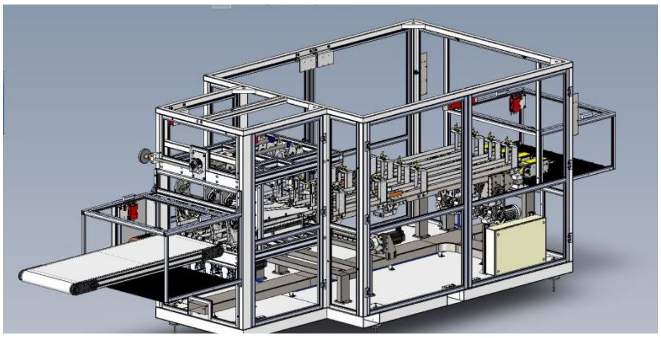


Figure 3.4 : Horizontal REDS intermediate

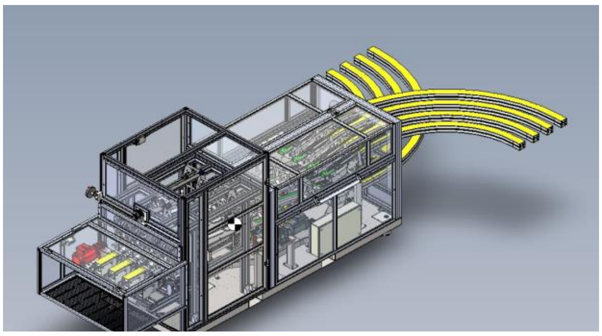


Figure 3.5 : vertical REDS intermediate

it is possible to launch sorted products.

The space needed is different upstream and downstream due to the different number of belt conveyors.

In figure 3.5, the products consumed by the REDS are supplied by a machine located upstream of it, called in this case "Producing Machine". This "production machine" needs downstream space to accumulate the products after processing. The machine located downstream of the REDS, called "Consumer Machine" also needs upstream space, where it is possible to keep the incoming products, before and during disposal. Furthermore, a short buffer space is required among those required by the different machines, to avoid the formation of a single product queue between the machines, and consequently avoid the stoppage of the entire production.

Figure 3.5: diagram of insertion of a REDS intermediate in a line

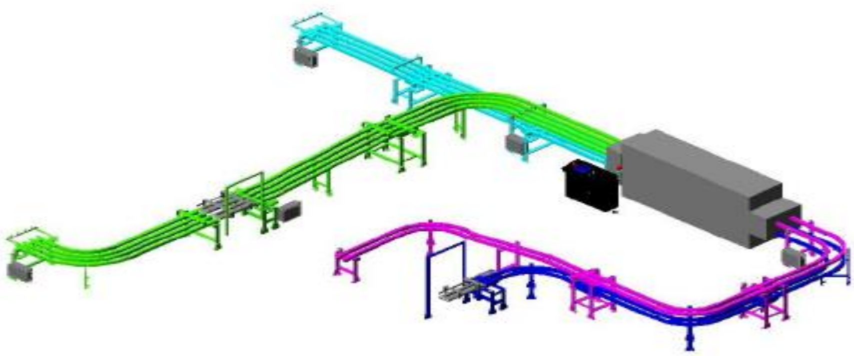


Figure 3.6: insertion of a REDS intermediate in a line

Given that the number of incoming and outgoing belt conveyors are not always multiples together, the product batches arriving at the machine, in order to have a complete balancing, must be multiples of both the incoming and outgoing conveyors. Each time this quantity of product reaches the REDS, a cycle is closed.

3.3 Mechanical arm of a REDS INTERMEDIATE

The most important component of an intermediate REDS is its mechanical arm, as it is the only active part of the device and has the task of being implemented to balance the product flow upstream and downstream. It is the heart of operations.

Depending on how it is designed and assembled, it makes it possible to optimize the system, improving one aspect rather than another. It is possible to minimize costs, to the detriment of the spaces, optimize space at the expense of time, and so on ...

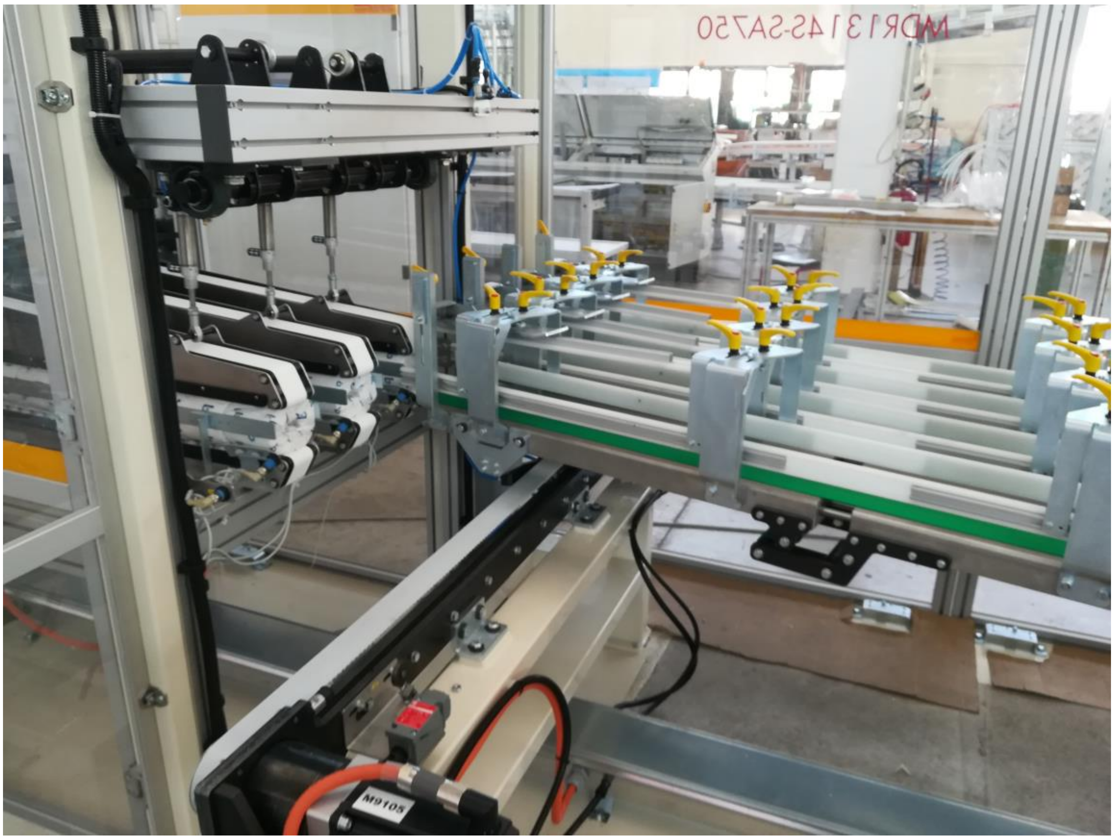


Figure 3.7: view of a mechanical arm of the REDS

There are 3 situations of interest in the design and assembly of the mechanical arm that lead to identifying important aspects:

- The mechanical arm is forced to move the same quantity of product on all the belt conveyors, or it can carry different quantities of product for each channel. Two operating strategies derive from it:
    - The first allows to launch, from one side to the other of the machine, a “launching unit” for each incoming or outgoing belt conveyor. This privileges the spaces, making the launches more frequent, and therefore the accumulation queues shorter. It is defined as a REVOLVER strategy.
    - The second one passes the quantity of product that leads to the upstream / downstream balancing, with the fewest number of possible launches. It uses slowing down and stop of the belt conveyors. It is the best for time spent, since the reduction in movements translates into a reduction in downtime. This is called TETRIS strategy.

- The arm is hinged upstream or downstream:
  The arm is generally placed on the side with fewer levels, both for practicality and for costs. For equal numbers of levels upstream and downstream, it is convenient to place the fulcrum where there is a smaller number of conveyors, since in this way it is possible to make it have a wider range of movements.

- The arm is composed of constrained (single arm) or independent conveyors, one from each other.

Using one solution instead of the other one leads to constraints on the strategies that can be adopted. The single arm allows only the TETRIS strategy, while the independent arm also allows the REVOLVER strategy.

3.4 The Launchers

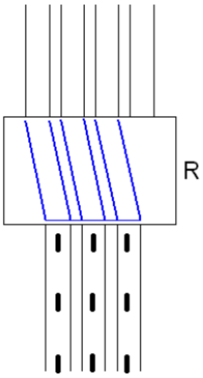
The launchers are very special component of the REDS intermediate. They can be defined as the operational part of the machine. The launchers define the “launching unit” of the operation. They are set in motion by an encoded motor that allows it to accurately launch a quantity of product length (launching unit), predefined by the operator, at a definite time interval. Once filled, the launchers must always be full of products, and these must always be well attached to each other in such a way that there is no space between them.

Figure 3.8: View of launchers

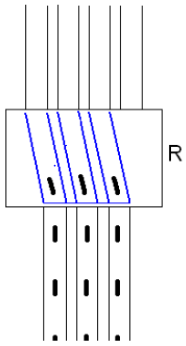
3.5 Operating Strategy

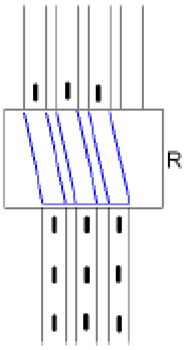
Remember that depending on how the mechanical arm is designed and assembled, two operating strategies are derived, named: REVOLVER strategy and TETRIS strategy. We will describe in more detail how they are implemented. We will focus on the case of a 3x4 REDS. (3 input channels and 4 output channels)

3.5.1 Revolver strategy



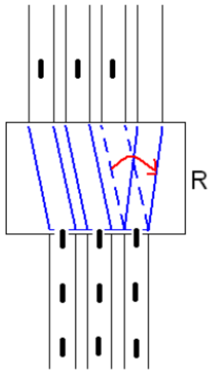
Step 1: Products (launching unit) arrive at the sorter via the belt conveyors that connect it to the "producing machine". A launching unit (of products, lots, etc.) transits simultaneously on each conveyor.

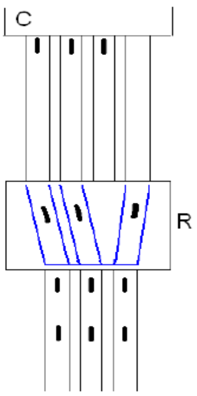


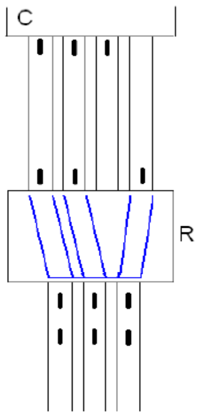


Step 2: A launching unit arrives at the entrance of the mechanical arm of the REDS. Other products follow this first row of products at a close distance.

Step 3: The arm changes its position, to allow subsequent products to fill different conveyors and thus balance the loads upstream and downstream of the sorter.

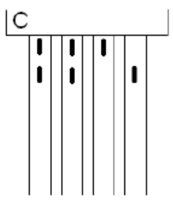


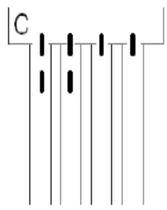




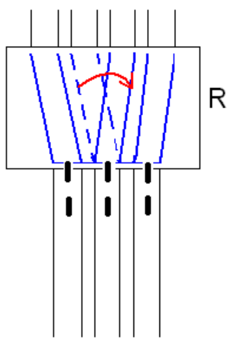
Step 4: A new series of products is received by the arm and transported to the exit of the REDS.

Meanwhile, the first series enters the "consumer machine". Here it stops because, since some channels are empty, the packing machine cannot yet work. Therefore, the products reached at the end of the conveyors are stopped, creating an accumulation.

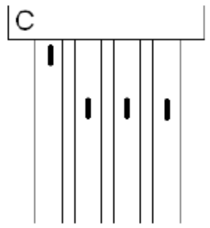




Step 5: At the arrival of the second series of product, which went to fill all the possible belt conveyors left empty previously, the first row is completed, and the consumer machine can work.



Step 6/7: During the cycle, when there is still no upstream and downstream balancing, other product rows must arrive, that will be sorted differently by the mechanical arm.

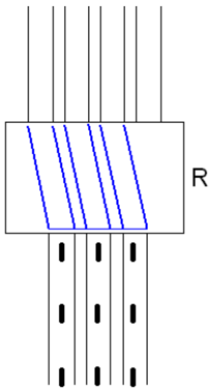


Step 8: The cycle closes, that is, there is the complete balance between the upstream and the downstream launching units. this occurs when the total transferred number of launching unit are multiple numbers of both incoming and outgoing channels each.

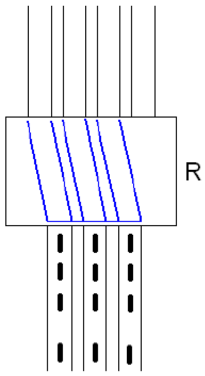
The transit of products from the incoming conveyors to the sorting arm can occur in two different ways:

- If there is enough time between one row of products and the next one, to allow the arm to change position without the need to stop the products at the entrance of the sorter, the flow is continuous.
- If launching units reach the diverter very close to each other, thus not giving the arm the possibility to change its position between one launched and the successive one, it is necessary to block the products before they are received by the arm, until this has not changed its position.

3.5.2 Tetris strategy



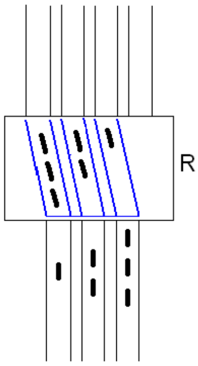
Step 1: Products arrive at the sorter via the conveyors that connect it to the "producing machine". A launching unit (of products, lots, etc.) transits simultaneously on each conveyor.

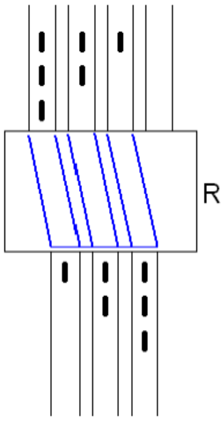


Step 2: Since the arm is managed in such a way as to consume a different number of launching units on each conveyor, it must wait for them to fill up with the required quantity.

This strategy allows, differently from the Revolver strategy, to be able to carry out a smaller number of movements, to the detriment of the accumulation space. Remember that the Revolver consume an equal number of upstream units on all conveyors.

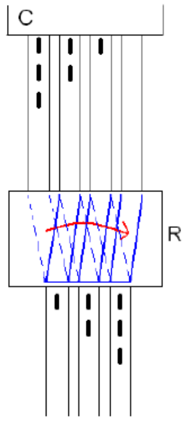
Step 3: When all the units to be launched are present, the arm transports the products to the exit of the sorter. Those that remain at the entrance, meanwhile, are rearranged for the next launch.

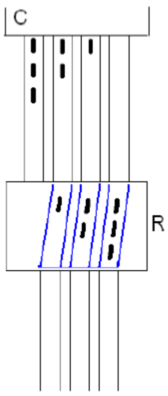




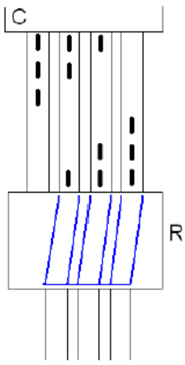
Step 4: The products come out from the arm, ending up on the outgoing channels of the diverter.

Step 5: The arm moves, connecting the incoming conveyors with the outgoing ones for a different distribution.

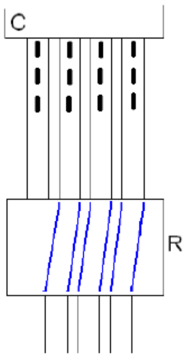




Step 6: If the products quantity present at the entrance of the machine is in greater or equal numbers than the ones required for the launch, then these are loaded on the arm and brought to the exit, otherwise they are blocked, and other products are expected to arrive.



In the meantime, it is possible that the products of the first launch came to the entrance of the "consumer machine". Due to the presence of empty conveyors, they stop and wait for the next launch to arrive.



Step 7: The second launch comes close to the consumer machine and reaches the previously launched products, thus completing the product rows.

At this point the "consumer machine" can bring in the products to process them.

The cycle ends when the total transferred launching unit are multiple numbers of both incoming and outgoing conveyors each.

3.6 Operating Modes and classification in families

Operating Modes

Since the number of incoming belt conveyors is general in a different quantity from those in output, it is possible to distinguish two operating modes of the REDS:

- Diverter mode: The number of input channels is smaller than the output one. The mechanical arm will then be normally hinged upstream.
- Combiner mode: The number of input channels is greater than the output one. The arm is normally hinged downstream.

In some cases, the REDS can be configured to work with the same number of input and output conveyors. This mode is called By-Pass.

Classification in families

An analysis of the numbers of incoming and outgoing conveyors of the REDS leads to a classification in families.

Combinations with entries and / or exits on more than one level work with the same strategies as those on a single entry and exit level that have the same number of conveyors.

So, all 210 possible configurations can be traced back to the basic ones:

1 → 2			
1 → 3	2 → 3		
1 → 4	2 → 4	3 → 4	
1 → 5	2 → 5	3 → 5	4 → 5

The two operating strategies are possible in almost all possible configurations, but in different ways, especially the Tetris one.

The differences required lead to dividing the various cases into families:

- Family A = Tetris missing.
  This includes all those combinations that contain individual conveyor and that, therefore, cannot be sorted according to a strategy that involves the Tetris strategy.

- Family B = Tetris with two launches
  Here we refer to the configurations that have a single conveyor gap between the inputs and outputs if we consider only one level.

- Family C = Tetris with three launches
  Characterize the situation in which the sorting operations can be realized with a launch from 3 to 5 conveyors and vice versa.

- Family D = Tetris with four launches
  This includes the combinations referable to a sorting from 2 to 5 conveyors and vice versa.

- Family E = Multiple peers (only for Revolver Strategy)
  This category includes configurations with conveyors that are multiple between them.

Each group can be divided into two subgroups that correspond to each operating mode: Diverter mode and Combiner mode.

Families B, C and D exploit both revolver strategy and Tetris strategy, while only the Revolver strategy can be applied to families A and E.

Below, will be reported the analysis for all families in different operating modes. This analysis is carried out taking into consideration the situation in which the rows of launching units useful for concluding a cycle arrive at the sorter all together and alone. This situation is purely ideal as launching units arrive at the sorter depending on how the producing machine operates upstream.

The launching sequence follows a fundamental rule, namely that it must ensure that the conveyors of each output level contain at least one unit with the fewest possible number of launches and, when this is verified, that the incoming conveyors are emptied in the same way.

Legend

S_L = *Upstream space, in launching unit, which must be occupied to be able to launch products.*

S_C = *Downstream space, in launching unit, necessary for the "consumer machine" to start working on the products.*

S_O = *Upstream space, in launching unit, which brings the upstream-downstream balance by level.*

C_{ICLO} = *upstream storage space, in launching unit, for complete upstream-Downstream balance.*

S_F = *Downstream space, in launching unit, occupied by all the launching units launched if the "consumer machine" does not start up.*

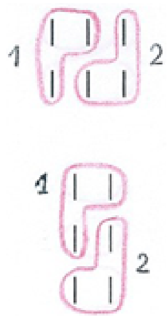
S_{CAMBI} = *Number of movements that the arm must perform to complete the CYCLE.*

Family B

2 → 3

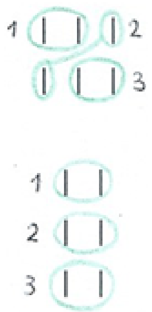
TETRIS

$S_L = 2u$
$S_C = 2u$
$S_O = 3u$
Ciclo = 3u
$S_F = 2u$
Scambi = 1



PARI

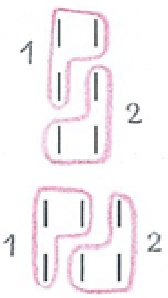
$S_L = 1u$
$S_C = 2u$
$S_O = 3u$
Ciclo = 3u
$S_F = 2u$
Scambi = 2



3 → 2

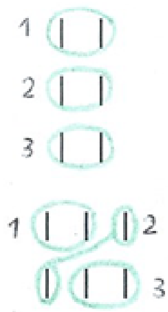
TETRIS

$S_L = 2u$
$S_C = 2u$
$S_O = 2u$
Ciclo = 2u
$S_F = 3u$
Scambi = 1



PARI

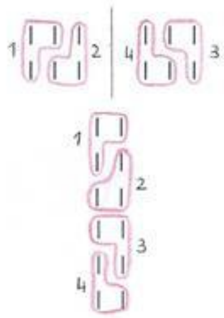
$S_L = 1u$
$S_C = 1u$
$S_O = 2u$
Ciclo = 2u
$S_F = 3u$
$A_{cc} = 1u$
Scambi = 2



2 → 3+3

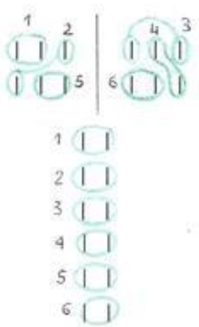
TETRIS

$S_L = 2u$
$S_C = 2u$
$S_O = 3u$
Ciclo = 6u
$S_F = 2u$
Scambi = 3



PARI

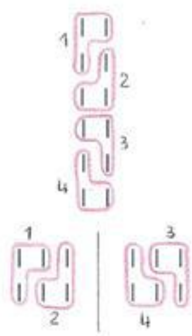
$S_L = 1u$
$S_C = 2u$
$S_O = 3u$
Ciclo = 6u
$S_F = 2u$
Scambi = 5



3+3 → 2

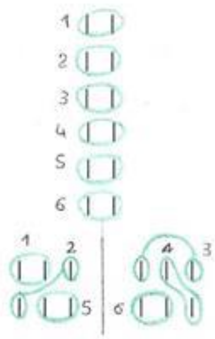
TETRIS

$S_L = 2u$
$S_C = 2u$
$S_O = 2u$
Ciclo = 2u
$S_F = 6u$
Scambi = 3



PARI

$S_L = 1u$
$S_C = 1u$
$S_O = 2u$
Ciclo = 2u
$S_F = 6u$
$A_{cc} = 1u$
Scambi = 5



2 → 3+3+3

TETRIS

$S_L = 2u$

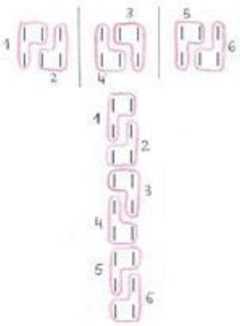
$S_C = 2u$

$S_0 = 3u$

CICLO = 9u

$S_F = 2u$

$S_{CAMBI} = 5$



PARI

$S_L = 1u$

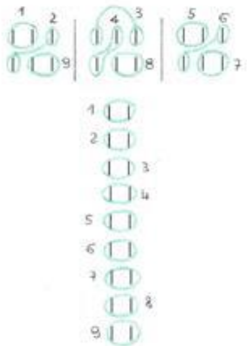
$S_C = 2u$

$S_0 = 3u$

CICLO = 9u

$S_F = 2u$

$S_{CAMBI} = 8$



3+3+3 → 2

TETRIS

$S_L = 2u$

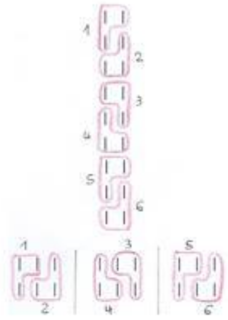
$S_C = 2u$

$S_0 = 2u$

CICLO = 2u

$S_F = 9u$

$S_{CAMBI} = 5$



PARI

$S_L = 1u$

$S_C = 1u$

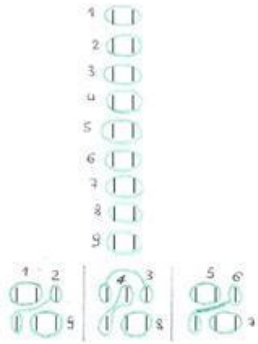
$S_0 = 2u$

CICLO = 2u

$S_F = 9u$

$A_{cc} = 1u$

$S_{CAMBI} = 8$



2+2 → 3

TETRIS

$S_L = 2u$

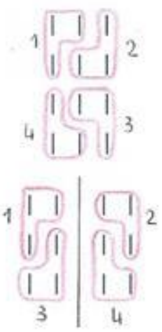
$S_C = 2u$

$S_0 = 3u$

CICLO = 3u

$S_F = 4u$

$S_{CAMBI} = 3$



PARI

$S_L = 1u$

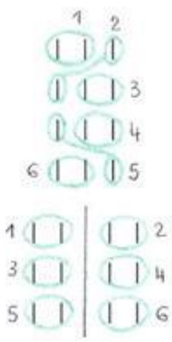
$S_C = 2u$

$S_0 = 3u$

CICLO = 3u

$S_F = 4u$

$S_{CAMBI} = 5$



3 → 2+2

TETRIS

$S_L = 2u$

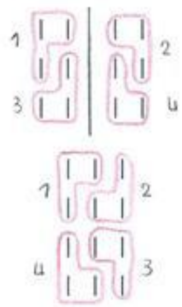
$S_C = 2u$

$S_0 = 2u$

CICLO = 4u

$S_F = 3u$

$S_{CAMBI} = 3$



PARI

$S_L = 1u$

$S_C = 1u$

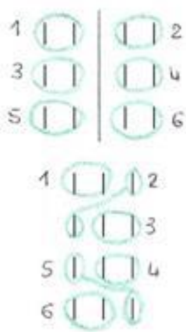
$S_0 = 2u$

CICLO = 4u

$S_F = 3u$

$A_{cc} = 1u$

$S_{CAMBI} = 5$



2+2 → 3+3+3

TETRIS

S_L = 2u

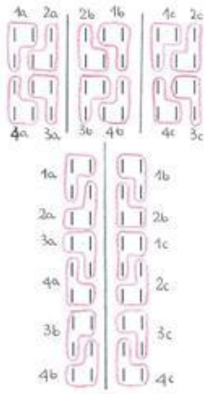
S_C = 2u

S_O = 3u

CICLO = 9u

S_F = 4u

S_{CAMBI} = 5



PARI

S_L = 1u

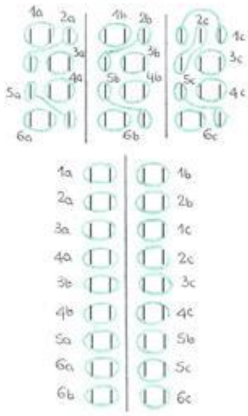
S_C = 2u

S_O = 3u

CICLO = 9u

S_F = 4u

S_{CAMBI} = 7



3+3+3 → 2+2

TETRIS

S_L = 2u

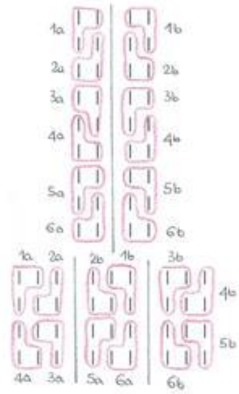
S_C = 2u

S_O = 2u

CICLO = 4u

S_F = 9u

S_{CAMBI} = 5



PARI

S_L = 1u

S_C = 1u

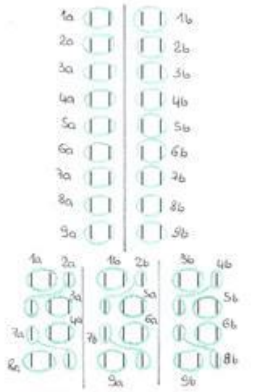
S_O = 2u

CICLO = 4u

S_F = 9u

A_{cc} = 1u

S_{CAMBI} = 7



2+2+2 → 3

TETRIS

S_L = 2u

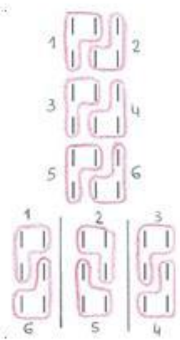
S_C = 2u

S_O = 3u

CICLO = 3u

S_F = 6u

S_{CAMBI} = 5



PARI

S_L = 1u

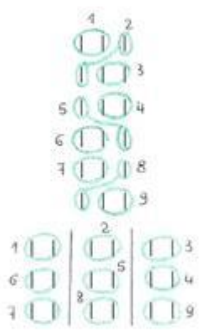
S_C = 2u

S_O = 3u

CICLO = 3u

S_F = 6u

S_{CAMBI} = 6



3 → 2+2+2

TETRIS

S_L = 2u

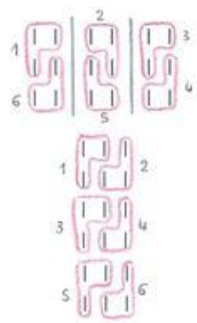
S_C = 2u

S_O = 2u

CICLO = 6u

S_F = 3u

S_{CAMBI} = 5



PARI

S_L = 1u

S_C = 1u

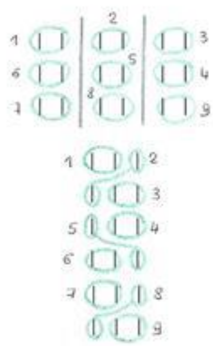
S_O = 2u

CICLO = 6u

S_F = 3u

A_{cc} = 1u

S_{CAMBI} = 6



2+2+2 → 3+3

TETRIS

S_L = 2u

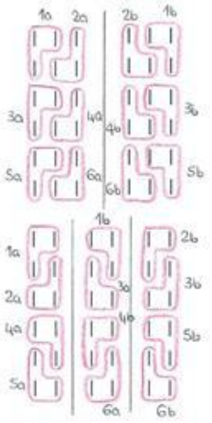
S_C = 2u

S_0 = 3u

Ciclo = 6u

S_F = 6u

Scambi = 5



PARI

S_L = 1u

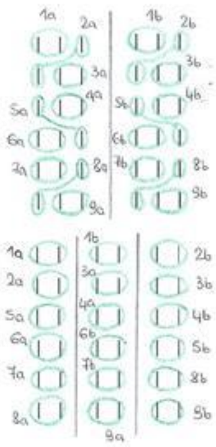
S_C = 2u

S_0 = 3u

Ciclo = 6u

S_F = 6u

Scambi = 6



3+3 → 2+2+2

TETRIS

S_L = 2u

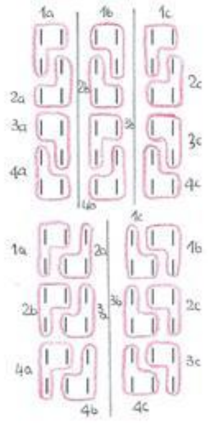
S_C = 2u

S_0 = 2u

Ciclo = 6u

S_F = 6u

Scambi = 5



PARI

S_L = 1u

S_C = 1u

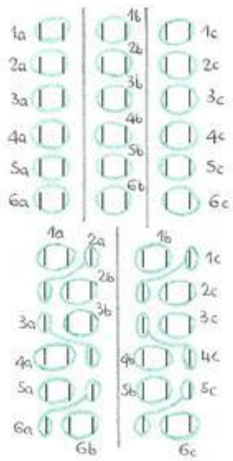
S_0 = 2u

Ciclo = 6u

S_F = 6u

Acc = 1u

Scambi = 6



3 → 4

TETRIS

S_L = 3u

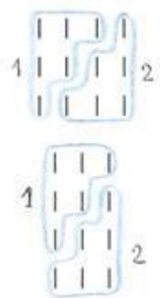
S_C = 3u

S_0 = 4u

Ciclo = 4u

S_F = 3u

Scambi = 1



PARI

S_L = 1u

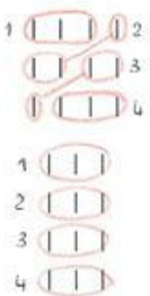
S_C = 2u

S_0 = 4u

Ciclo = 4u

S_F = 3u

Scambi = 3



4 → 3

TETRIS

S_L = 3u

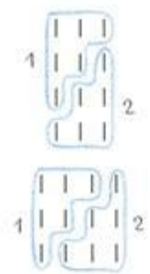
S_C = 3u

S_0 = 3u

Ciclo = 3u

S_F = 4u

Scambi = 1



PARI

S_L = 1u

S_C = 1u

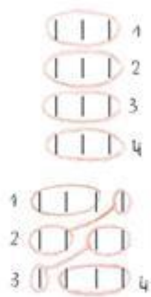
S_0 = 3u

Ciclo = 3u

S_F = 4u

Acc = 1u

Scambi = 3



3 → 4+4

TETRIS

S_L = 3u

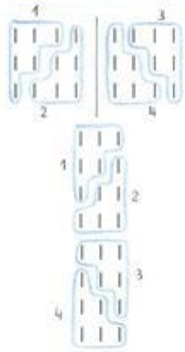
S_C = 3u

S_0 = 4u

Ciclo = 8u

S_F = 3u

S_{CAMBI} = 3



PARI

S_L = 1u

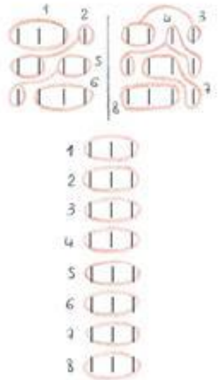
S_C = 2u

S_0 = 4u

Ciclo = 8u

S_F = 3u

S_{CAMBI} = 7



4+4 → 3

TETRIS

S_L = 3u

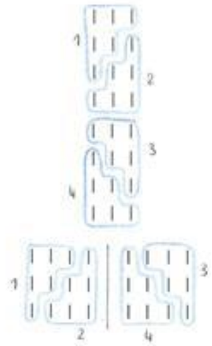
S_C = 3u

S_0 = 3u

Ciclo = 3u

S_F = 8u

S_{CAMBI} = 3



PARI

S_L = 1u

S_C = 1u

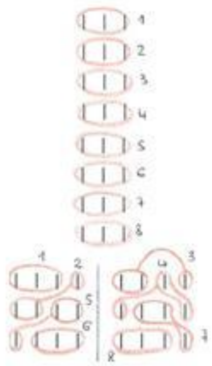
S_0 = 3u

Ciclo = 3u

S_F = 8u

A_{cc} = 1u

S_{CAMBI} = 7



3 → 4+4+4

TETRIS

S_L = 3u

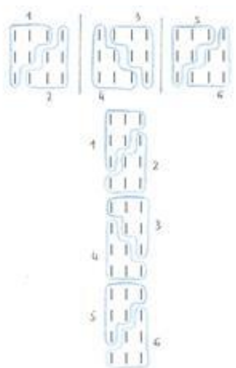
S_C = 3u

S_0 = 4u

Ciclo = 12u

S_F = 3u

S_{CAMBI} = 5



PARI

S_L = 1u

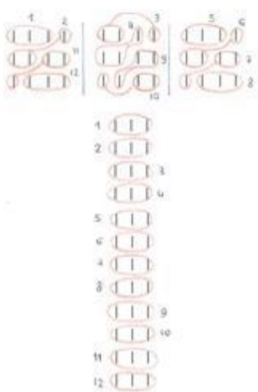
S_C = 2u

S_0 = 4u

Ciclo = 12u

S_F = 3u

S_{CAMBI} = 11



4+4+4 → 3

TETRIS

S_L = 3u

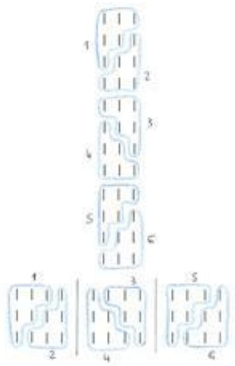
S_C = 3u

S_0 = 3u

Ciclo = 3u

S_F = 12u

S_{CAMBI} = 5



PARI

S_L = 1u

S_C = 1u

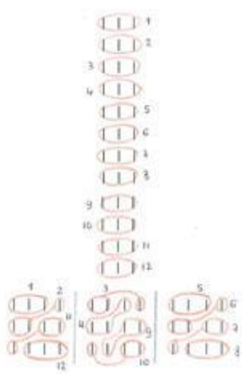
S_0 = 3u

Ciclo = 3u

S_F = 12u

A_{cc} = 1u

S_{CAMBI} = 11



3+3 → 4

TETRIS

S_L = 3u

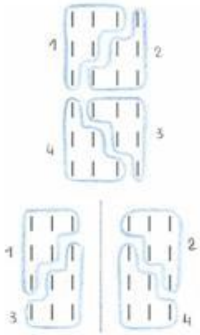
S_C = 3u

S_0 = 4u

CICLO = 4u

S_F = 6u

SCAMBI = 3



PARI

S_L = 1u

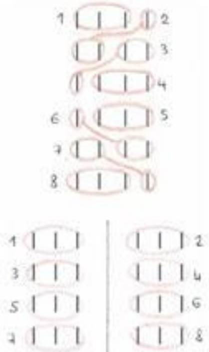
S_C = 2u

S_0 = 4u

CICLO = 4u

S_F = 6u

SCAMBI = 7



4 → 3+3

TETRIS

S_L = 3u

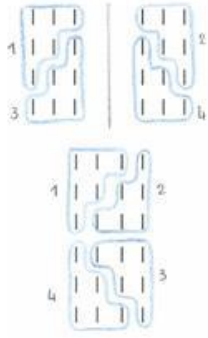
S_C = 3u

S_0 = 3u

CICLO = 6u

S_F = 4u

SCAMBI = 3



PARI

S_L = 1u

S_C = 1u

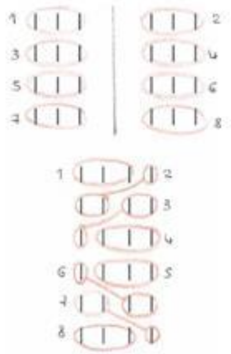
S_0 = 3u

CICLO = 6u

S_F = 4u

A_{cc} = 1u

SCAMBI = 7



3+3 → 4+4+4

TETRIS

S_L = 3u

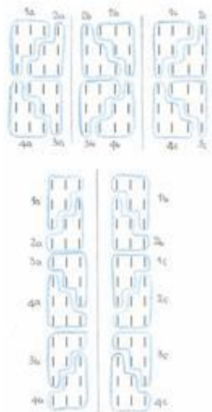
S_C = 3u

S_0 = 4u

CICLO = 12u

S_F = 6u

SCAMBI = 5



PARI

S_L = 1u

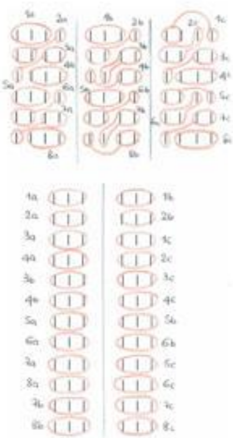
S_C = 2u

S_0 = 4u

CICLO = 12u

S_F = 6u

SCAMBI = 11 (10)



4+4+4 → 3+3

TETRIS

S_L = 3u

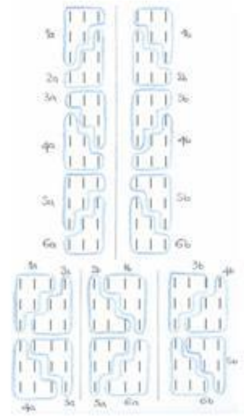
S_C = 3u

S_0 = 3u

CICLO = 6u

S_F = 12u

SCAMBI = 5



PARI

S_L = 1u

S_C = 1u

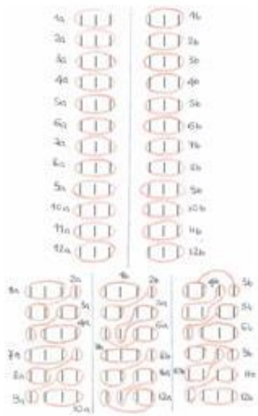
S_0 = 3u

CICLO = 6u

S_F = 12u

A_{cc} = 1u

SCAMBI = 11



3+3+3 → 4

TETRIS

$S_L = 3u$

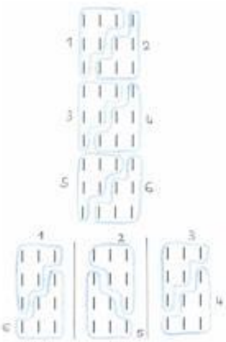
$S_C = 3u$

$S_0 = 4u$

$C_{ICLO} = 4u$

$S_F = 9u$

$S_{CAMBI} = 5$



4 → 3+3+3

TETRIS

$S_L = 3u$

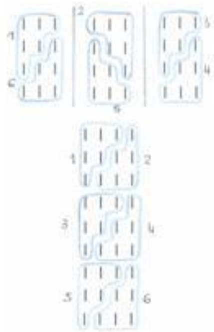
$S_C = 3u$

$S_0 = 3u$

$C_{ICLO} = 9u$

$S_F = 4u$

$S_{CAMBI} = 5$



PARI

$S_L = 1u$

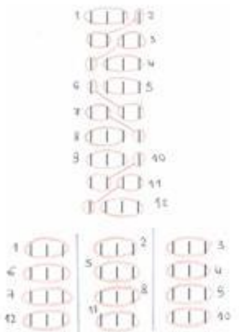
$S_C = 2u$

$S_0 = 4u$

$C_{ICLO} = 4u$

$S_F = 9u$

$S_{CAMBI} = 11$



PARI

$S_L = 1u$

$S_C = 1u$

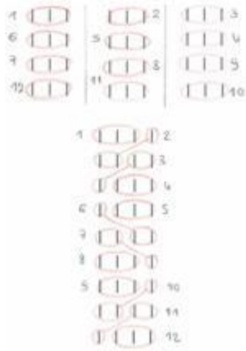
$S_0 = 3u$

$C_{ICLO} = 9u$

$S_F = 4u$

$A_{cc} = 1u$

$S_{CAMBI} = 11$



3+3+3 → 4+4

TETRIS

$S_L = 3u$

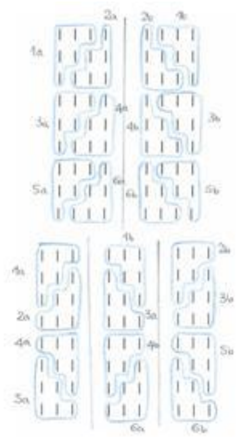
$S_C = 3u$

$S_0 = 4u$

$C_{ICLO} = 8u$

$S_F = 9u$

$S_{CAMBI} = 5$



4+4 → 3+3+3

TETRIS

$S_L = 3u$

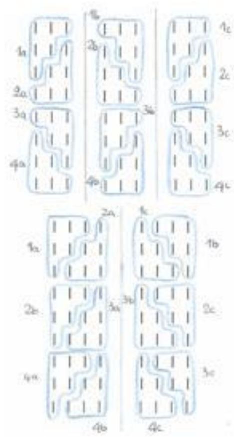
$S_C = 3u$

$S_0 = 3u$

$C_{ICLO} = 9u$

$S_F = 8u$

$S_{CAMBI} = 5$



PARI

$S_L = 1u$

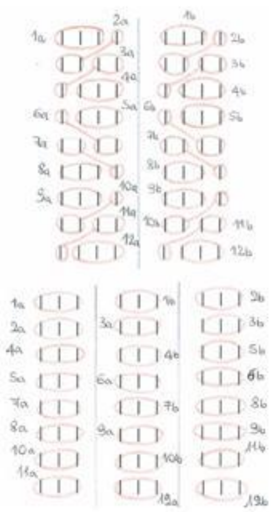
$S_C = 2u$

$S_0 = 4u$

$C_{ICLO} = 8u$

$S_F = 9u$

$S_{CAMBI} = 11$



PARI

$S_L = 1u$

$S_C = 1u$

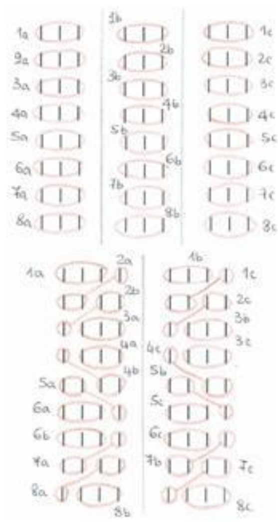
$S_0 = 3u$

$C_{ICLO} = 9u$

$S_F = 8u$

$A_{cc} = 1u$

$S_{CAMBI} = 11$



4 → 5

TETRIS

S_L = 4u

S_C = 4u

S_0 = 5u

C_{ICLO} = 5u

S_F = 4u

S_{CAMBI} = 1

PARI

S_L = 1u

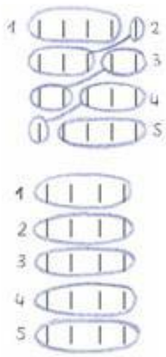
S_C = 2u

S_0 = 5u

C_{ICLO} = 5u

S_F = 4u

S_{CAMBI} = 4



5 → 4

TETRIS

S_L = 4u

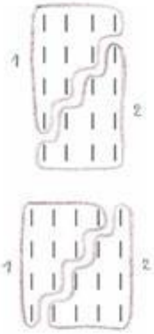
S_C = 4u

S_0 = 4u

C_{ICLO} = 4u

S_F = 5u

S_{CAMBI} = 1



PARI

S_L = 1u

S_C = 1u

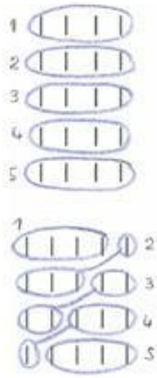
S_0 = 4u

C_{ICLO} = 4u

S_F = 5u

A_{cc} = 1u

S_{CAMBI} = 4



4 → 5+5

S_L = 4u

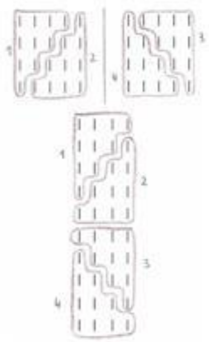
S_C = 4u

S_0 = 5u

C_{ICLO} = 10u

S_F = 4u

S_{CAMBI} = 3



PARI

S_L = 1u

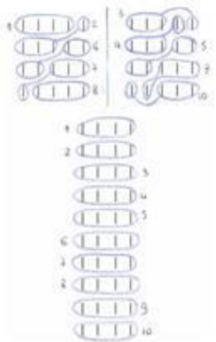
S_C = 2u

S_0 = 5u

C_{ICLO} = 10u

S_F = 4u

S_{CAMBI} = 9



5+5 → 4

TETRIS

S_L = 4u

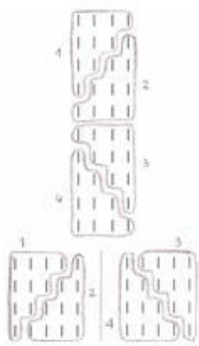
S_C = 4u

S_0 = 4u

C_{ICLO} = 4u

S_F = 10u

S_{CAMBI} = 3



PARI

S_L = 1u

S_C = 1u

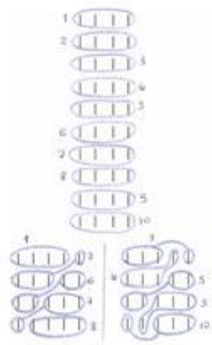
S_0 = 4u

C_{ICLO} = 4u

S_F = 10u

A_{cc} = 1u

S_{CAMBI} = 9



4 → 5+5+5

TETRIS

S_L = 4u

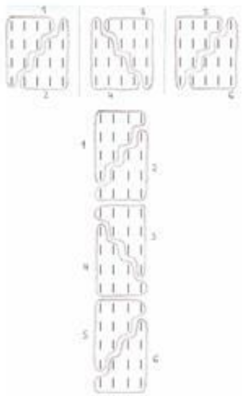
S_C = 4u

S_0 = 5u

CICLO = 15u

S_F = 4u

S_{CAMBI} = 5



PARI

S_L = 1u

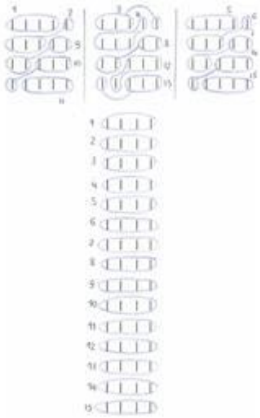
S_C = 2u

S_0 = 5u

CICLO = 15u

S_F = 4u

S_{CAMBI} = 14



5+5+5 → 4

TETRIS

S_L = 4u

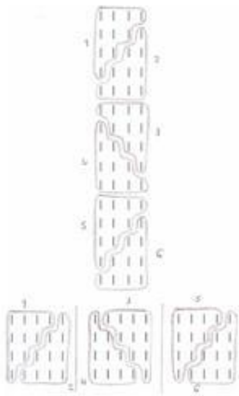
S_C = 4u

S_0 = 4u

CICLO = 4u

S_F = 15u

S_{CAMBI} = 5



PARI

S_L = 1u

S_C = 1u

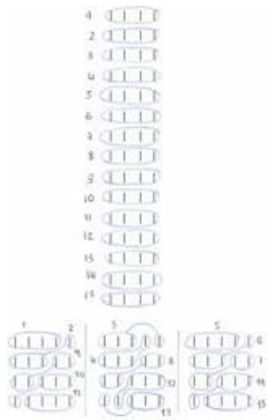
S_0 = 4u

CICLO = 4u

S_F = 15u

A_{cc} = 1u

S_{CAMBI} = 14



4+4 → 5

TETRIS

S_L = 4u

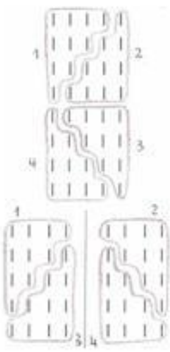
S_C = 4u

S_0 = 5u

CICLO = 5u

S_F = 8u

S_{CAMBI} = 3



PARI

S_L = 1u

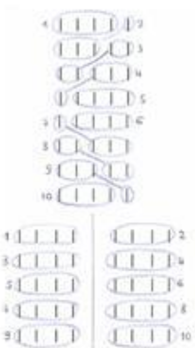
S_C = 2u

S_0 = 5u

CICLO = 5u

S_F = 8u

S_{CAMBI} = 9



5 → 4+4

TETRIS

S_L = 4u

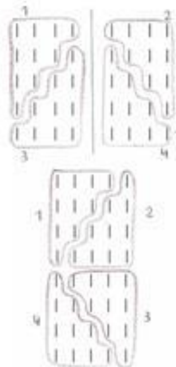
S_C = 4u

S_0 = 4u

CICLO = 8u

S_F = 5u

S_{CAMBI} = 3



PARI

S_L = 1u

S_C = 1u

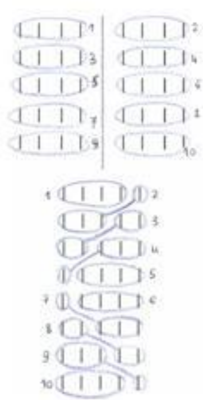
S_0 = 4u

CICLO = 8u

S_F = 5u

A_{cc} = 1u

S_{CAMBI} = 9



4+4 → 5+5+5

TETRIS

$S_L = 4u$

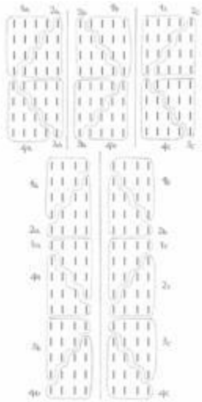
$S_C = 4u$

$S_0 = 5u$

$C_{ICLO} = 15u$

$S_F = 8u$

$S_{CAMBI} = 5$



PARI

$S_L = 1u$

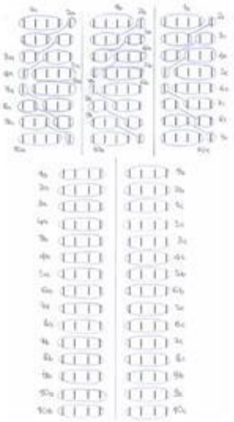
$S_C = 2u$

$S_0 = 5u$

$C_{ICLO} = 15u$

$S_F = 8u$

$S_{CAMBI} = 13$



5+5+5 → 4+4

TETRIS

$S_L = 4u$

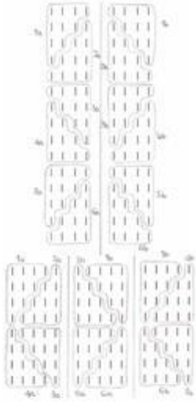
$S_C = 4u$

$S_0 = 4u$

$C_{ICLO} = 8u$

$S_F = 15u$

$S_{CAMBI} = 5$



PARI

$S_L = 1u$

$S_C = 1u$

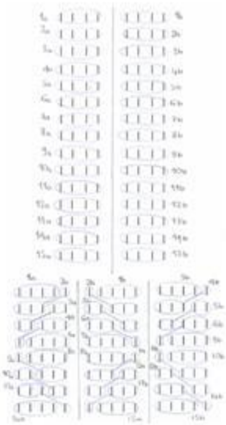
$S_0 = 4u$

$C_{ICLO} = 8u$

$S_F = 15u$

$A_{cc} = 1u$

$S_{CAMBI} = 13$



4+4+4 → 5

TETRIS

$S_L = 4u$

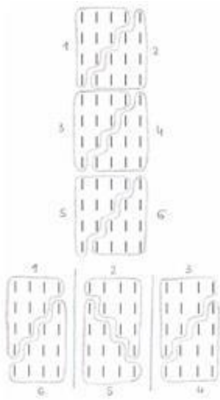
$S_C = 4u$

$S_0 = 5u$

$C_{ICLO} = 5u$

$S_F = 12u$

$S_{CAMBI} = 5$



PARI

$S_L = 1u$

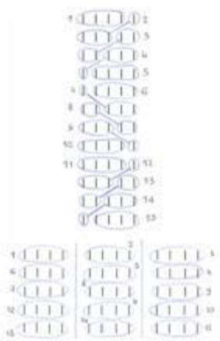
$S_C = 2u$

$S_0 = 5u$

$C_{ICLO} = 5u$

$S_F = 12u$

$S_{CAMBI} = 14$



5 → 4+4+4

TETRIS

$S_L = 4u$

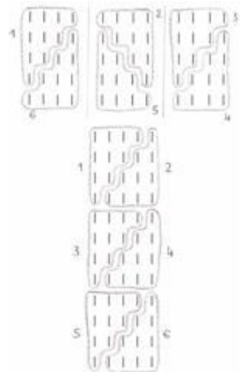
$S_C = 4u$

$S_0 = 4u$

$C_{ICLO} = 12u$

$S_F = 5u$

$S_{CAMBI} = 5$



PARI

$S_L = 1u$

$S_C = 1u$

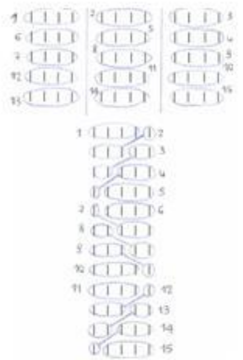
$S_0 = 4u$

$C_{ICLO} = 12u$

$S_F = 5u$

$A_{cc} = 1u$

$S_{CAMBI} = 14$



4+4+4 → 5+5

TETRIS

$S_L = 4u$

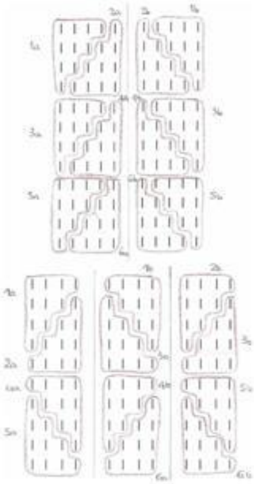
$S_C = 4u$

$S_0 = 5u$

$C_{ICLO} = 10u$

$S_F = 12u$

$S_{CAMBI} = 5$



PARI

$S_L = 1u$

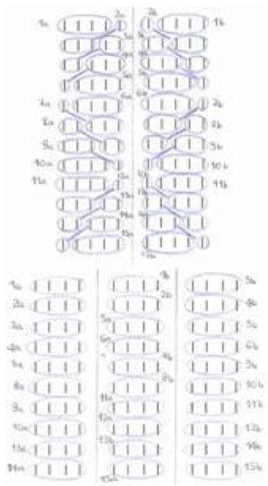
$S_C = 2u$

$S_0 = 5u$

$C_{ICLO} = 10u$

$S_F = 12u$

$S_{CAMBI} = 13$



5+5 → 4+4+4

TETRIS

$S_L = 4u$

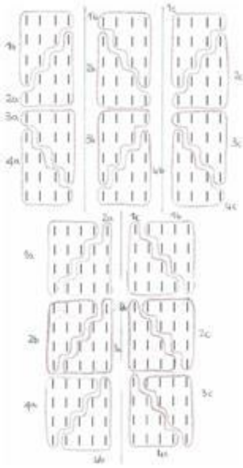
$S_C = 4u$

$S_0 = 4u$

$C_{ICLO} = 12u$

$S_F = 10u$

$S_{CAMBI} = 5$



PARI

$S_L = 1u$

$S_C = 1u$

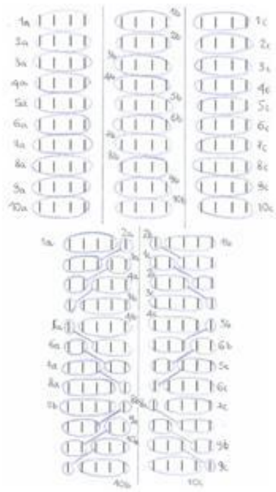
$S_0 = 4u$

$C_{ICLO} = 12u$

$S_F = 10u$

$A_{cc} = 1u$

$S_{CAMBI} = 13$



Family C

3 → 5

TETRIS

S_L = 3u/1u

S_C = 3u

S_0 = 5u

C_{ICLO} = 5u

S_F = 3u

S_{CAMBI} = 2

PARI

S_L = 1u

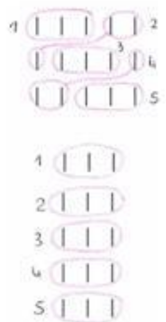
S_C = 2u/3u

S_0 = 5u

C_{ICLO} = 5u

S_F = 3u

S_{CAMBI} = 4



5 → 3

TETRIS

S_L = 3u/1u

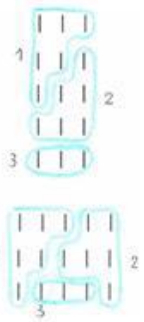
S_C = 3u/1u

S_0 = 3u

C_{ICLO} = 3u

S_F = 5u

S_{CAMBI} = 2



PARI

S_L = 1u

S_C = 1u

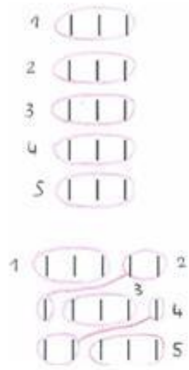
S_0 = 3u

C_{ICLO} = 3u

S_F = 5u

A_{cc} = 1u

S_{CAMBI} = 4



3 → 5+5

TETRIS

S_L = 3u/1u

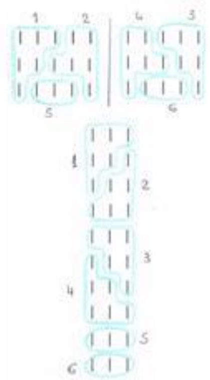
S_C = 3u

S_0 = 5u

C_{ICLO} = 10u

S_F = 3u

S_{CAMBI} = 5



PARI

S_L = 1u

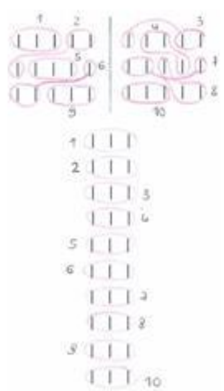
S_C = 2u/3u

S_0 = 5u

C_{ICLO} = 10u

S_F = 3u

S_{CAMBI} = 9



5+5 → 3

TETRIS

S_L = 3u/1u

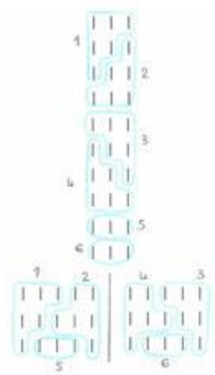
S_C = 3u/1u

S_0 = 3u

C_{ICLO} = 3u

S_F = 10u

S_{CAMBI} = 5



PARI

S_L = 1u

S_C = 1u

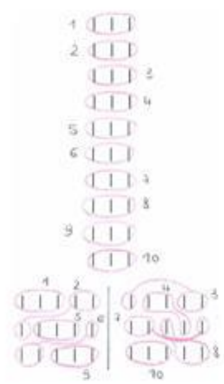
S_0 = 3u

C_{ICLO} = 3u

S_F = 10u

A_{cc} = 1u

S_{CAMBI} = 9



3 → 5+5+5

TETRIS

S_L = 3u/1u

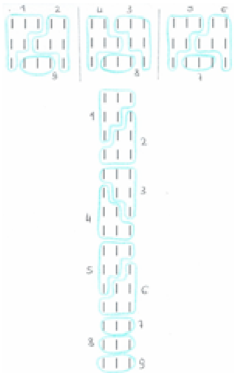
S_C = 3u

S_0 = 5u

C_{ICLO} = 15u

S_F = 3u

S_{CAMBI} = 8



PARI

S_L = 1u

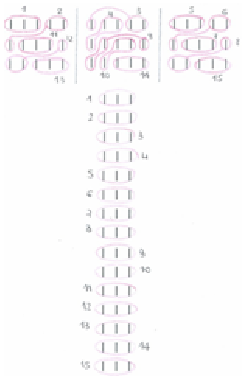
S_C = 2u/3u

S_0 = 5u

C_{ICLO} = 15u

S_F = 3u

S_{CAMBI} = 14



5+5+5 → 3

TETRIS

S_L = 3u/1u

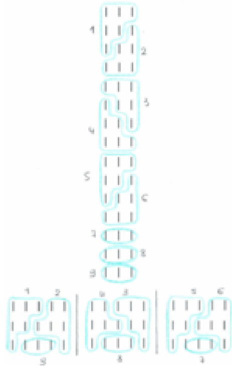
S_C = 3u/1u

S_0 = 3u

C_{ICLO} = 3u

S_F = 15u

S_{CAMBI} = 8



PARI

S_L = 1u

S_C = 1u

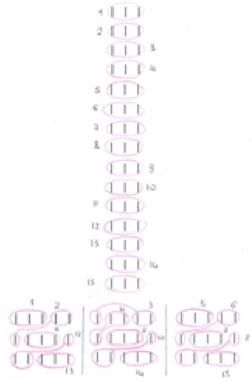
S_0 = 3u

C_{ICLO} = 3u

S_F = 15u

A_{cc} = 1u

S_{CAMBI} = 14



3+3 → 5

TETRIS

S_L = 3u/1u

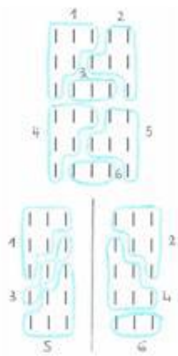
S_C = 3u

S_0 = 5u

C_{ICLO} = 5u

S_F = 6u

S_{CAMBI} = 5



PARI

S_L = 1u

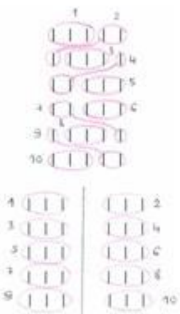
S_C = 2u/3u

S_0 = 5u

C_{ICLO} = 5u

S_F = 6u

S_{CAMBI} = 9



5 → 3+3

TETRIS

S_L = 3u/1u

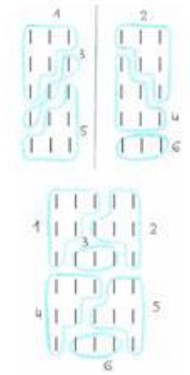
S_C = 3u/1u

S_0 = 3u

C_{ICLO} = 6u

S_F = 5u

S_{CAMBI} = 5



PARI

S_L = 1u

S_C = 1u

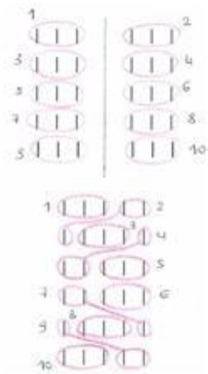
S_0 = 3u

C_{ICLO} = 6u

S_F = 5u

A_{cc} = 1u

S_{CAMBI} = 9



3+3 → 5+5+5

TETRIS

S_L = 3u/1u

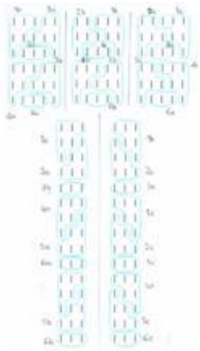
S_C = 3u

S_0 = 5u

C_{ICLO} = 15u

S_F = 6u

S_{CAMBI} = 8



PARI

S_L = 1u

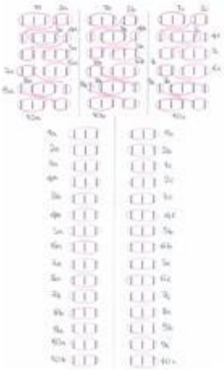
S_C = 2u/3u

S_0 = 5u

C_{ICLO} = 15u

S_F = 6u

S_{CAMBI} = 13



5+5+5 → 3+3

TETRIS

S_L = 3u/1u

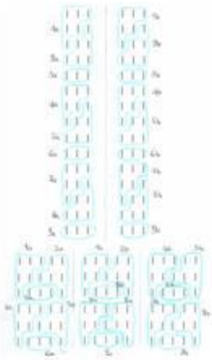
S_C = 3u/1u

S_0 = 3u

C_{ICLO} = 6u

S_F = 15u

S_{CAMBI} = 8



PARI

S_L = 1u

S_C = 1u

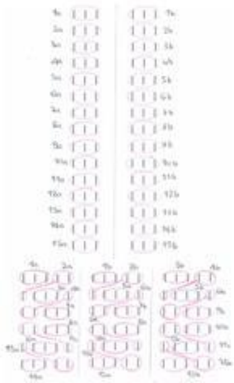
S_0 = 3u

C_{ICLO} = 6u

S_F = 15u

A_{cc} = 1u

S_{CAMBI} = 13



3+3+3 → 5

TETRIS

S_L = 3u/1u

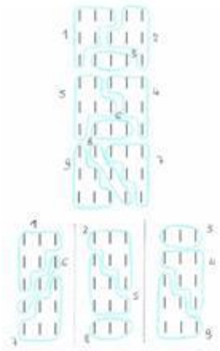
S_C = 3u

S_0 = 5u

C_{ICLO} = 5u

S_F = 9u

S_{CAMBI} = 8



PARI

S_L = 1u

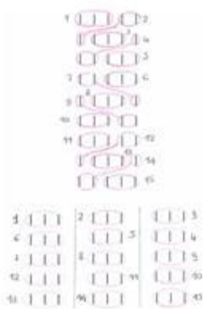
S_C = 2u/3u

S_0 = 5u

C_{ICLO} = 5u

S_F = 9u

S_{CAMBI} = 14



5 → 3+3+3

TETRIS

S_L = 3u/1u

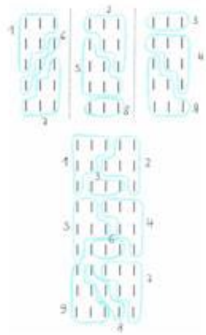
S_C = 3u/1u

S_0 = 3u

C_{ICLO} = 9u

S_F = 5u

S_{CAMBI} = 8



PARI

S_L = 1u

S_C = 1u

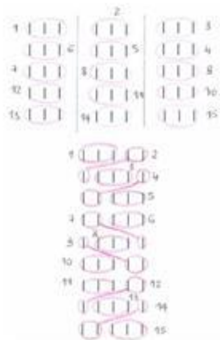
S_0 = 3u

C_{ICLO} = 9u

S_F = 5u

A_{cc} = 1u

S_{CAMBI} = 14



3+3+3 → 5+5

TETRIS

S_L = 3u/1u

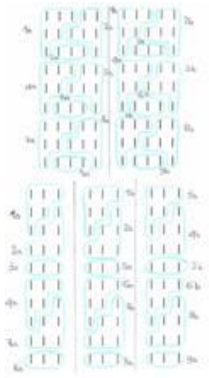
S_C = 3u

S_0 = 5u

C_{ICLO} = 10u

S_F = 9u

S_{CAMBI} = 8



PARI

S_L = 1u

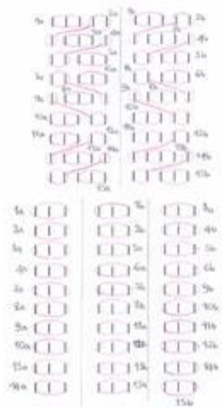
S_C = 2u/3u

S_0 = 5u

C_{ICLO} = 10u

S_F = 9u

S_{CAMBI} = 13



5+5 → 3+3+3

TETRIS

S_L = 3u/1u

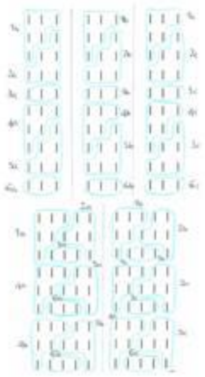
S_C = 3u/1u

S_0 = 3u

C_{ICLO} = 9u

S_F = 10u

S_{CAMBI} = 8



PARI

S_L = 1u

S_C = 1u

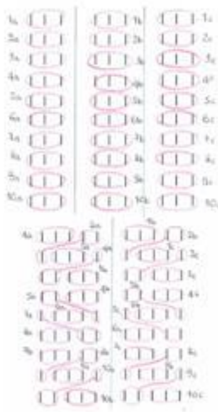
S_0 = 3u

C_{ICLO} = 9u

S_F = 10u

A_{cc} = 1u

S_{CAMBI} = 13



Family D

2 → 5

TETRIS

S_L = 2u/1u

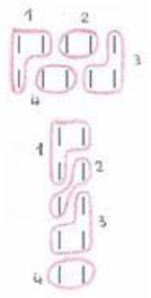
S_C = 2u

S_0 = 5u

CICLO = 5u

S_F = 2u

SCAMBI = 3



PARI

S_L = 1u

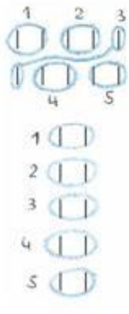
S_C = 2u

S_0 = 5u

CICLO = 5u

S_F = 2u

SCAMBI = 4



5 → 2

TETRIS

S_L = 2u/1u

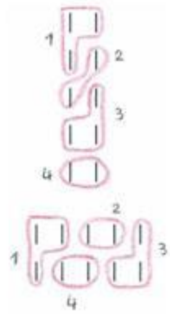
S_C = 2u/1u

S_0 = 2u

CICLO = 2u

S_F = 5u

SCAMBI = 3



PARI

S_L = 1u

S_C = 1u

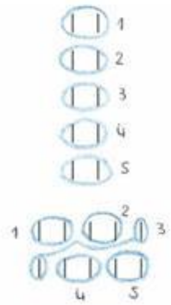
S_0 = 2u

CICLO = 2u

S_F = 5u

A_{cc} = 1u

SCAMBI = 4



2 → 5+5

TETRIS

S_L = 2u/1u

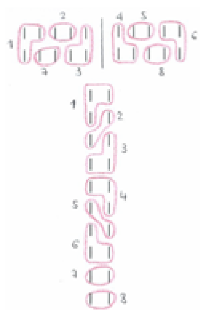
S_C = 2u

S_0 = 5u

CICLO = 10u

S_F = 2u

SCAMBI = 7



PARI

S_L = 1u

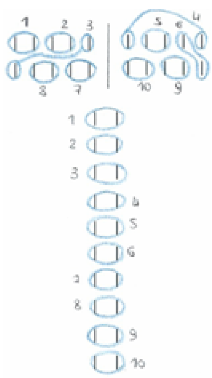
S_C = 2u

S_0 = 5u

CICLO = 10u

S_F = 2u

SCAMBI = 9



5+5 → 2

TETRIS

S_L = 2u/1u

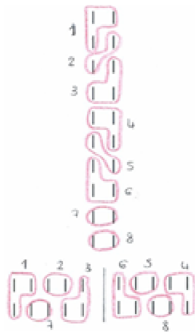
S_C = 2u/1u

S_0 = 2u

CICLO = 2u

S_F = 10u

SCAMBI = 7



PARI

S_L = 1u

S_C = 1u

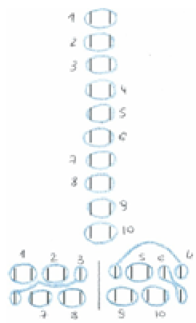
S_0 = 2u

CICLO = 2u

S_F = 10u

A_{cc} = 1u

SCAMBI = 9



2 → 5+5+5

TETRIS

S_L = 2u/1u

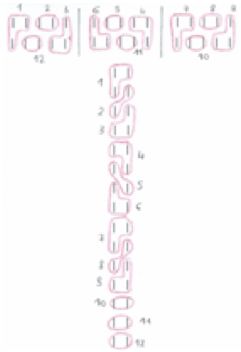
S_C = 2u

S_0 = 5u

CICLO = 15u

S_F = 2u

S_{CAMBI} = 11



5+5+5 → 2

TETRIS

S_L = 2u/1u

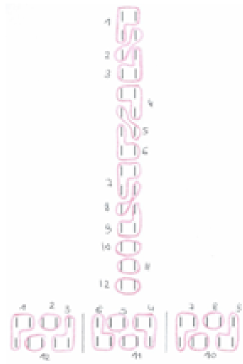
S_C = 2u/1u

S_0 = 2u

CICLO = 2u

S_F = 15u

S_{CAMBI} = 11



PARI

S_L = 1u

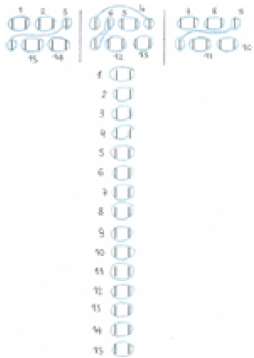
S_C = 2u

S_0 = 5u

CICLO = 15u

S_F = 2u

S_{CAMBI} = 14



PARI

S_L = 1u

S_C = 1u

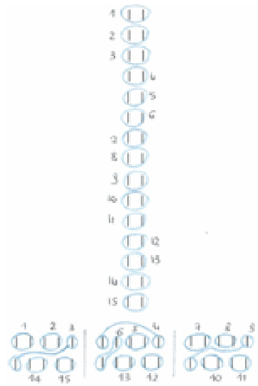
S_0 = 2u

CICLO = 2u

S_F = 15u

A_{cc} = 1u

S_{CAMBI} = 14



2+2 → 5

TETRIS

S_L = 2u/1u

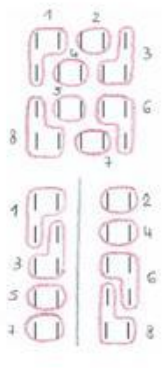
S_C = 2u

S_0 = 5u

CICLO = 5u

S_F = 4u

S_{CAMBI} = 7



5 → 2+2

TETRIS

S_L = 2u/1u

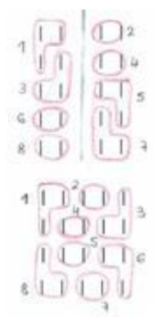
S_C = 2u/1u

S_0 = 2u

CICLO = 4u

S_F = 5u

S_{CAMBI} = 7



PARI

S_L = 1u

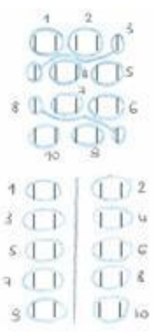
S_C = 2u

S_0 = 5u

CICLO = 5u

S_F = 4u

S_{CAMBI} = 9



PARI

S_L = 1u

S_C = 1u

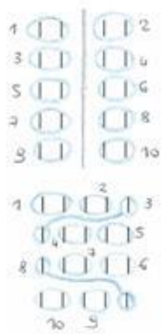
S_0 = 2u

CICLO = 4u

S_F = 5u

A_{cc} = 1u

S_{CAMBI} = 9



2+2 → 5+5+5

TETRIS

S_L = 2u/1u

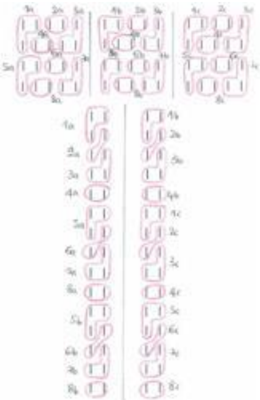
S_C = 2u

S_0 = 5u

C_{ICLO} = 15u

S_F = 4u

S_{CAMBI} = 11



PARI

S_L = 1u

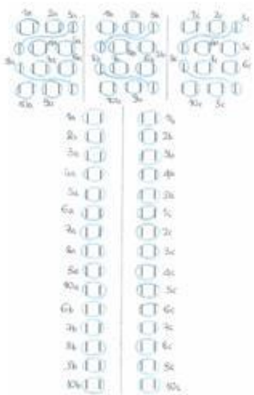
S_C = 2u

S_0 = 5u

C_{ICLO} = 15u

S_F = 4u

S_{CAMBI} = 14



5+5+5 → 2+2

TETRIS

S_L = 2u/1u

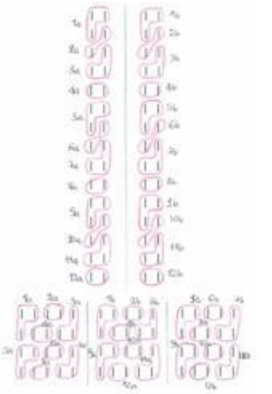
S_C = 2u/1u

S_0 = 2u

C_{ICLO} = 4u

S_F = 15u

S_{CAMBI} = 11



PARI

S_L = 1u

S_C = 1u

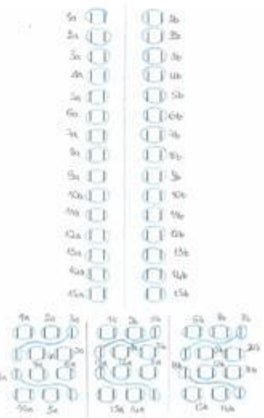
S_0 = 2u

C_{ICLO} = 4u

S_F = 15u

A_{cc} = 1u

S_{CAMBI} = 14



2+2+2 → 5

TETRIS

S_L = 2u/1u

S_C = 2u

S_0 = 5u

C_{ICLO} = 5u

S_F = 6u

S_{CAMBI} = 11

PARI

S_L = 1u

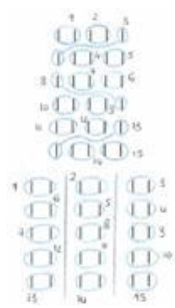
S_C = 2u

S_0 = 5u

C_{ICLO} = 5u

S_F = 6u

S_{CAMBI} = 14



5 → 2+2+2

TETRIS

S_L = 2u/1u

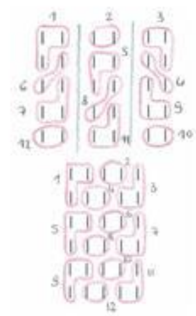
S_C = 2u/1u

S_0 = 2u

C_{ICLO} = 6u

S_F = 5u

S_{CAMBI} = 11



PARI

S_L = 1u

S_C = 1u

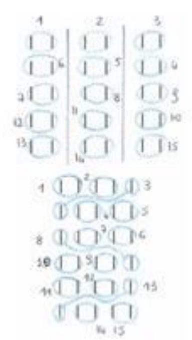
S_0 = 2u

C_{ICLO} = 6u

S_F = 5u

A_{cc} = 1u

S_{CAMBI} = 14



2+2+2 → 5+5

TETRIS

$S_L = 2u/1u$

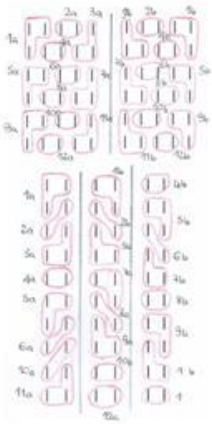
$S_C = 2u$

$S_0 = 5u$

$C_{ICLO} = 10u$

$S_F = 6u$

$S_{CAMBI} = 11$



5+5 → 2+2+2

TETRIS

$S_L = 2u/1u$

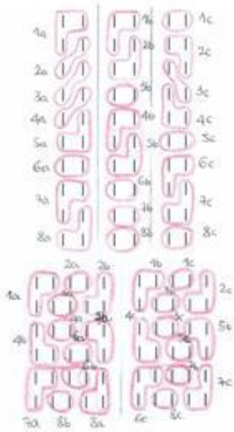
$S_C = 2u/1u$

$S_0 = 2u$

$C_{ICLO} = 6u$

$S_F = 10u$

$S_{CAMBI} = 11$



PARI

$S_L = 1u$

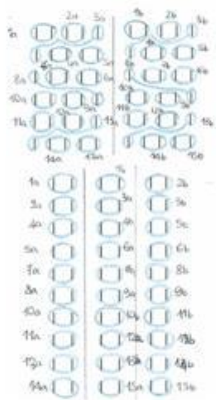
$S_C = 2u$

$S_0 = 5u$

$C_{ICLO} = 10u$

$S_F = 6u$

$S_{CAMBI} = 14$ (12)



PARI

$S_L = 1u$

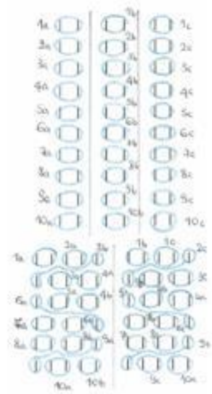
$S_C = 1u$

$S_0 = 2u$

$C_{ICLO} = 6u$

$S_F = 10u$

$S_{CAMBI} = 14$ (12)



Chapter 4

Dynamic Simulation of practical operations of REDS INTERMEDIATES and relative balancing of the lines in the tissue sector.

This chapter deal with the dynamic simulation of the operations of a **REDS INTERMEDIATE** inserted in a simplified production line**.**

The goal is therefore to derive a powerful dynamic model that can simulate a large range of REDS intermediate that could work in different operating modes (DIVERTER, COMBINER and By-pass modes) and containing all operating strategies (REVOLVER and TETRIS strategies).

This was possible with the aid of a powerful simulation tool called **PLS DYNAMIC/ TISSUEPLS DYNAMIC.**

It is important to emphasize that we will deal in this part with a simplified production line since we are interested in just getting the REDS INTERMEDIATE model. For this reason, we will work with a production line consisting of two machines: A LOGSAW MACHINE and A REDS INTERMEDIATE. This choice will be justified later.

4.1 PLS DYNAMIC and Plant Simulation

PLS Dynamic (Pulsar Layout Simulator) is a new simulation service developed by the company Pulsar Engineering, using the SIEMENS software "Plant Simulation". The software is a powerful tool offering a 2D and 3D interface and is capable of:

- Predicting the functional behavior of a new line before its physical construction, ensuring a reduction of risks and costs.

- Optimizing existing plants and evaluating the effects of changes on the line, without operating directly on the machines.
- Representing a real converting, packaging and palletizing line.
- Simulating in real time:
    - Products
    - Processes
    - Sensors along the line
    - Electric drives
    - Processing Machines
    - Conveyors
    - REDS (Rolls Exchange Divider System)
- Analyzing the events and checking their effects on production

This tool allows to obtain important results such as:

- Total production
- Detail of each pallet at the end of the line (weight, format, branch of origin)
- consumption material of each machine present along the line
- production costs

Thanks to Pulsar Dynamic PLS, customers and operators can therefore experience the real functioning of the line before the purchase of all the machines. It allows also the customers to experience the difference between a line with Pulsar Harmonizer software installed and a line where operators set all parameters.

4.2 Model Design

One of the powerful features of the software is that it offers the possibility to design the model in 2D and 3D interface. However, it is appropriate to develop the model starting from the 2D interface, thus allowing to focus the attention on the design of the model. The 3D interface will therefore be used in the test phase, where it will be necessary to better visualize the machines and their components during the simulation.

It is important to note that the two interfaces are strictly related, since, by building a model on one of the interfaces, the software offers by default the construction of the same model on the other interface.

4.2.1 Simulation setting

1. **Personal Folders**

Plant Simulation provides an important library called "class library", containing different basic components grouped in folders, that can be used to model a large range of machines. In addition to these folders, the software also allows the creation of personal folders for users. This flexibility allows a better orientation to the specific project for each user.

For the project in examination, two sets of personal folders have been created: A first set called "machines", containing all the machines connected in the simplified line; and a second set called "oggetti", containing a series of components necessary for the construction of the machines in connection. It is necessary to make a brief discussion to justify the choices made on each of these sets.

a) The folder "Machines"

As we said above, since we are focused on obtaining a REDS INTERMEDIATE model, we just need a simplified model of a production line that will allow us to analyze the behavior of the machine in study.

For this reason, we need to simulate the product flow entering the REDS intermediate. This justifies the choice of a LOGSAW machine positioned upstream, which can fully ensure this function. The choice of a LOGSAW machine is also closely related to the fact that we are dealing with a production line in the tissue sector.

Note that to evaluate and analyze the product flow downstream of REDS INTERMEDIATE, it will be enough to add conveyor belts.

The "machines" folder is therefore composed of two machines required for simulation: A LOGSAW machine and a REDS INTERMEDIATE.

b) The folder "Oggetti"

This set contains a series of basic components, which have been modified and adapted according to the requirements, and which, in addition to other unmodified basic component, will be used to build our simplified production line.

It was necessary to create seven components for this set. These components are essentially belt conveyors.

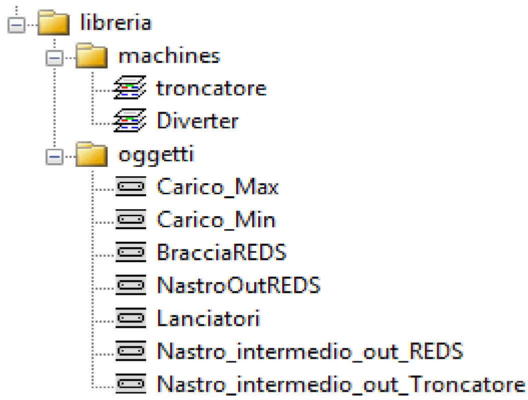


Figure 4.1 Personal folders

2. The 2D/3D model construction

As stated above, the model will be developed on the 2D interface, and the 3D interface that will be offered (by default) by the software will be used for visualization in the simulation phase.

The frame consists of two machines connected by multiples belt conveyors.

a) The 2D LOGSAW machine

Let’s remember that a LOGSAW machine, thanks to the use of a blade, cuts the logs into paper rolls of the chosen length and sends them to the subsequent packaging stations.
From this remark, it is obvious that to have a simplified model of a LOGSAW machine, it is necessary:

- an infinite source of LOG production: this justifies the choice of the component called "Source" which can fully guarantee this functionality.

- one or more log cutting channels: this is the fundamental element of this machine because it defines two fundamental parameters: the number of paper rolls per log, and the number of paper rolls produced per minute for each belt conveyors.
  To manage this feature, the ideal element provided by the library is called "SingleProc", which has been renamed "TaglioX", with X an integer to distinguish each channel.

- A conveyor for each cutting channel, allowing the products to be transported to the next workstation. These conveyors have the particularity of slightly increasing the speed of the products leaving the cutting channels, to promote a fluid and continuous flow. These conveyors have been renamed "Nastro_intermedio_X", with X an integer to distinguish each conveyor.

All these elements are linked through connectors, and their actions will be controlled and managed through programming methods (INIT and MetodoTagliPersi) which will be the subject of further study later.

In figure 4.2, it is possible to observe the 2D simplified model of the LOGSAW machine. We can note the presence of several general variables.

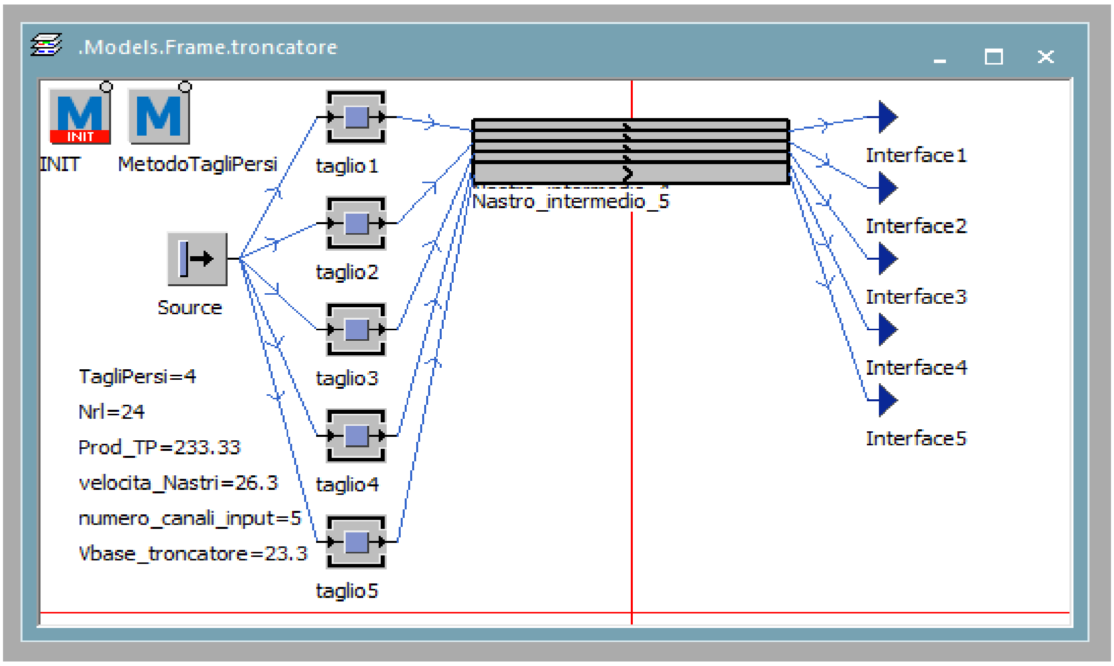


Figure 4.2: View of the 2D logsaw machine

b) The 2D REDS intermediate

A singular line of our model of REDS intermediate is composed by six elements which are essentially conveyors, but with various functionalities:

- A first conveyor which receives the products coming from the machine upstream. This conveyor makes it possible to manage a first accumulation flow in input, by means of a photocell sensor installed at a well-defined distance from it.
  This element is part of the personal folder created and takes the name of "Carico_Max" in relation to the function of the sensor which is dedicated to him. A more detailed analysis will be made on the functions of the evoked sensor in a dedicated section.

- A second conveyor connected upstream to the one mentioned above and linked downstream to the box of the REDS intermediate. It makes it possible to manage a lower number of products compared to the first one, and thus takes the name of "Carico_Min "in the personal folder. Even in this case, its name is related to the function of the mounted photocell sensor, which will be analyzed in another dedicated section.

- A launcher, which is a very special conveyor and is the operational part of the machine. Once filled, the launcher must always be full of products, and these must always be well attached to each other in such a way that there is no space between them. The launcher is set in motion by an encoded motor that allows it to accurately launch a quantity of product length (launching unit), predefined by the operator, at a definite time interval. In our personal folder, the launcher can be found under the name “lanciatori”.

- The mechanical arm, which is the most important component of REDS, has the distinction of being the only moving element as indicated in section 3.3. It thus carries the role of balancing the flow of product upstream and downstream. In our personal folder it is called "BracciaREDS".

- a REDS output conveyor, which allows the products to be transported to the next machine. Its name in the folder "oggetti" is "Nastro_intermedio_out_REDS".

- The last component that is just used for simulation is called "Drain". It is a downstream process. The Drain removes the products and records the statistics necessary for the users.

Figure 4.4 shows the 2D model of the intermediate REDS. It is possible to note in this figure a set of programming methods, general variables and tables.

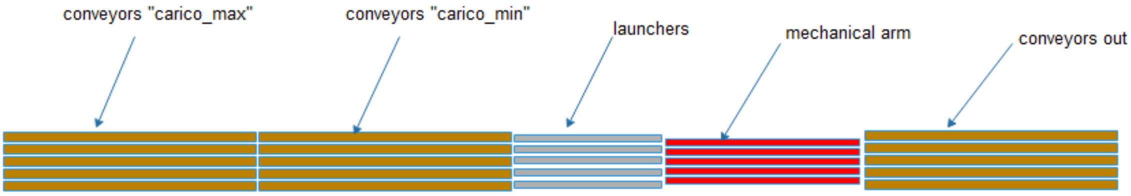


Figure 4.3: Diagram of a REDS intermediate

The variables used in the 2D model have been divided into types for easy use. we distinguish:

- the variables related to the configuration: They are variables that allow the user to define the operating mode, the strategy of launching and the number of channels in input and output.

- state variables: They are variables conditioning the operation of the machine, and therefore by which decisions are made.

- The variables related to the structure: Here are grouped the variables which make it possible to modify parameters of structures such as conveyors length and sensors positions.

- The variables of the excel file: they are variables provided by the company Pulsar and which define parameters of operation.

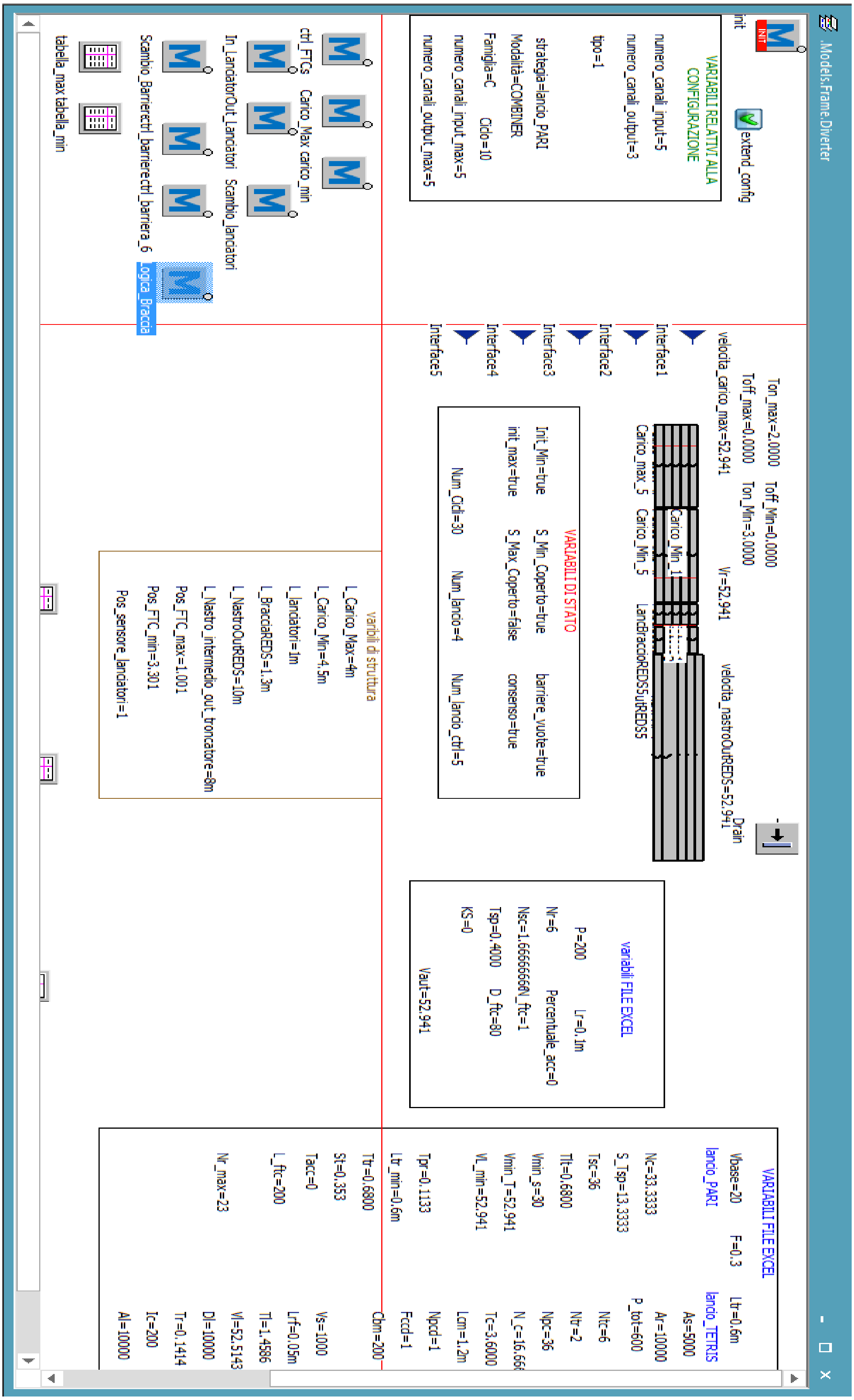


Figure 4.4: View of the 2D REDS intermediate model

4.2.2 Sensors

This section discusses the features of sensors used in the REDS intermediate model. It is important to point out that most of the sensors used on the transmission line are photocell sensors since we are usually interested in recording the presence / absence of products at certain well-defined points. These photocell sensors are arranged along the line through suitable structures which hold them above the conveyors.

The signal of each sensor is interpreted as follows:

- If the sensor detects the presence of the product for a time exceeding a minimum set time, the signal is interpreted as "full conveyor".

- If the sensor does not detect the presence of the product for a time exceeding a set minimum time, the signal is interpreted as "empty conveyor".

- If the status of the sensor changes in less time than the filter time, it means that the sensor is intercepted alternatively by the products, which are always separated by a certain empty space. This alternation of signal is interpreted as "Product in motion".

Figure 4.5 and 4.6 show simplified diagrams of the REDS with the location of the different sensors hinged upstream and downstream respectively. It is possible to distinguish five classes of sensors partitioned in three groups:

- Start/Stop sensors: Their role is to give the signal to set the conveyors in motion when certain conditions are verified.

    - The first one is the "maximum load sensor" and is positioned on the first conveyor in the direction of arrival of products ("Carico_max").

It defines the minimum length of products for which the REDS will be authorized to carry out its first launch. It is the “start sensor”.

- The second one is the "minimum load sensor" and is positioned on the conveyor "carico_min", successive to the one mentioned above. It allows the stops in phase of the machine when there is absence of products upstream. It is the “stop sensor”.

- Launcher sensors: There are two. One located at the entrance and the other one at the exit.

  - The one located at the entrance has the function of detecting the presence of the first product arriving at the entrance of the launcher and block it until accumulation of the minimum number of products required by the launcher. It is a no-load starting sensor.

  - The one located at the exit is used for rephasing products after each launch, when certain conditions are verified.

- The barrier of photocell sensors: This is a series of sensors generally spaced from each other by a distance less than the length of the product. As shown in figure 4.5 and 4.6, they are positioned on the mechanical arm and at the correspondence of the switching area.

There are usually several conveyors in parallel and it is often necessary to provide detecting logics along the line to manage groups of sensors having the same role placed on conveyors in parallel. Depending on the desired operating conditions, it is possible to decide the general state. The most common schemes in the case of a 5-way transport system:

- Functionality 5-5: The "Full conveyor" signal is indicated when all 5 photocells are covered for a certain time, the "Empty conveyor" signal is processed when all 5 photocells are discovered.

- Functionality 5-1: In this case the "Empty conveyor" signal is identified as valid when even just one photocell of the group is discovered for a certain time.

- Functionality 1-5: We have a "Full conveyor" signal as soon as the first photocell is covered for the minimum preset time. The “empty conveyor” signal is identified when all the 5 photocell sensors are uncovered.

However, for the case of the intermediate REDS which is the subject of our study, the following functionality has been implemented:

- For the start/stop sensors (maximum and minimum load sensors):

  - The "Full conveyor" signal is valid when only the photocells of the conveyors concerned by the next launch are covered for a certain time.

  - Vice versa, the "empty conveyor" signal is valid when just one of the photocells of the conveyors concerned by the next launch are uncovered for a certain time.

- For the barrier of photocell sensors:

  - The “Full conveyor” signal is set to valid when just one of the photocell sensors is covered.

  - The “empty conveyor” signal is set to valid when all photocell sensors are not covered.

Note that for the launcher sensors, we do not need to define a detecting logic, but just to detect the presence / absence of the products. Detecting logics are needed just in cases of start/stop sensors and the barrier of photocell sensors.

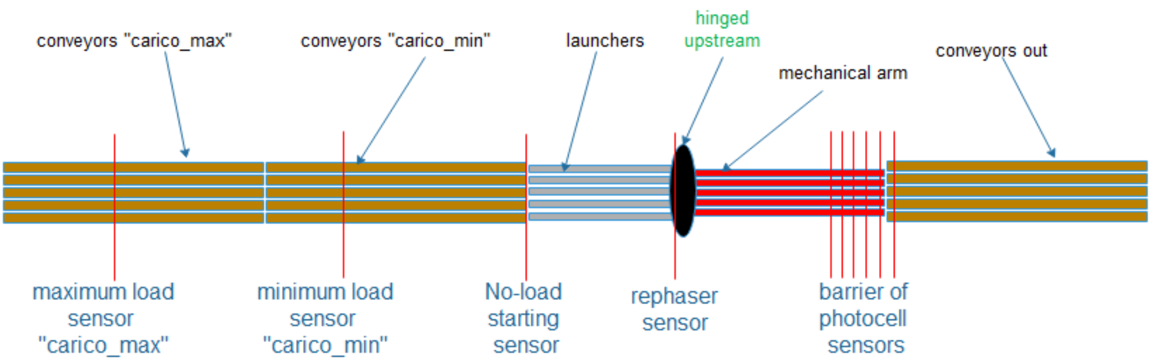


Figure 4.5: Diagram of REDS intermediate with sensors: Mechanical arm hinged upstream

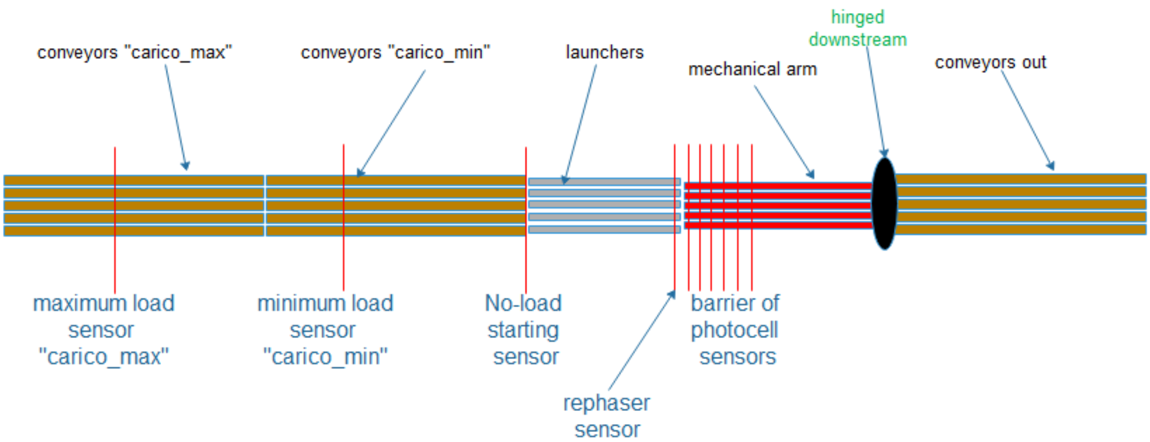


Figure 4.6: Diagram of REDS intermediate with sensors: mechanical arm hinged downstream

Figure 4.7: Example of START/STOP sensors

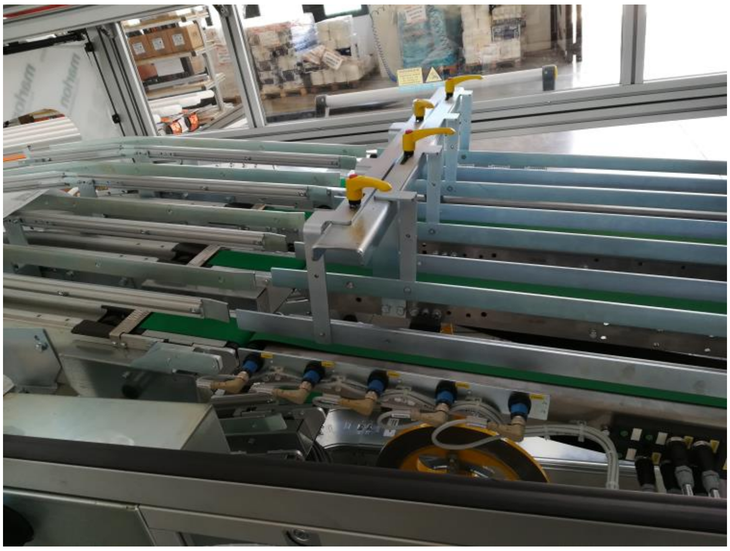


Figure 4.8: Example of Barrier of photocell sensors

Figure 4.9: Example of Rephasing sensors positioned on launchers

4.2.3 Flowcharts

The REDS intermediate has a well-defined operating logic. This is a set of actions and control operations performed on the products along their passage through the machine. It is therefore necessary to provide a system management algorithm. This algorithm is based on the signals provided by the different sensors installed on the line.

To facilitate understanding, we will define the practical operation of the REDS intermediate through flowcharts. We will need two flowcharts as the REDS performs two general asynchronous functions:

- Perform the launches (figure 4.7): The control action can be divided into two parts:
  - An initialization phase: This part defines the initial behavior of the REDS, from the reception of the first products (Feeding of the REDS) until the verification of the necessary conditions to perform the first launched. The objective in this operation is to accumulate an enough quantity of products to promote the good functioning at steady state.

    In this phase, for simulation purpose, the control action is performed only on the first product of each conveyor. Other products are just affected by the decisions made for each action.

  - A steady state phase: This phase describes the functioning of REDS in steady state. It is necessary:

    - To ensure that all conditions are met to perform a launch. (Typically, we need to ensure that there are enough products in the buffer.)
    - To perform the launch
    - To ensure that the distribution is correctly done.

- Distribute the products (figure 4.8): This is performed by the mechanical arm. We must ensure the correct distribution of product based on the signals provided by the barrier of photocell sensors.

The figures above show the operating flowcharts of the REDS intermediate. In the first, related to the performing of launches, it is possible to distinguish the two phases mentioned above. The initialization phase is green, and the steady state phase is blue. The second represents the flowchart describing the operations performed to correctly distribute the products.

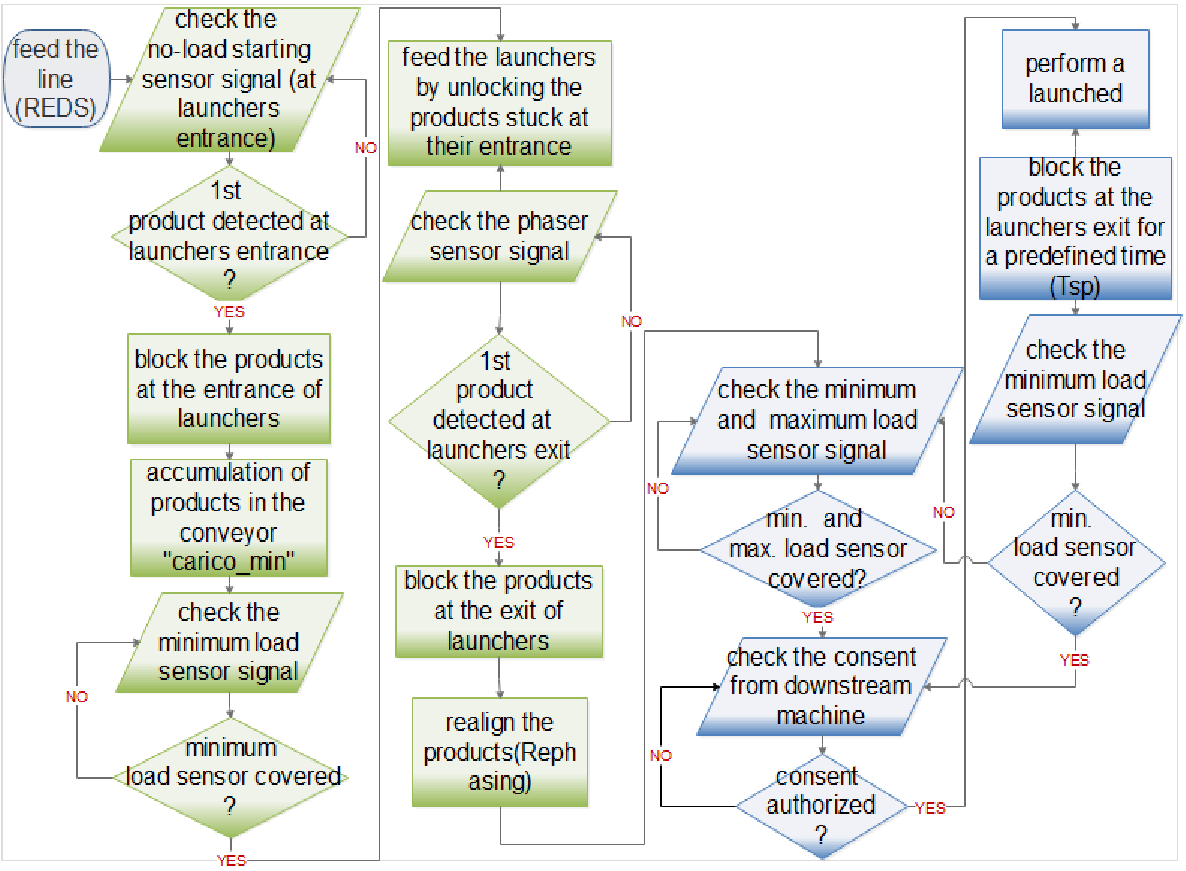


Figure 4.10: Flowchart to perform a launch

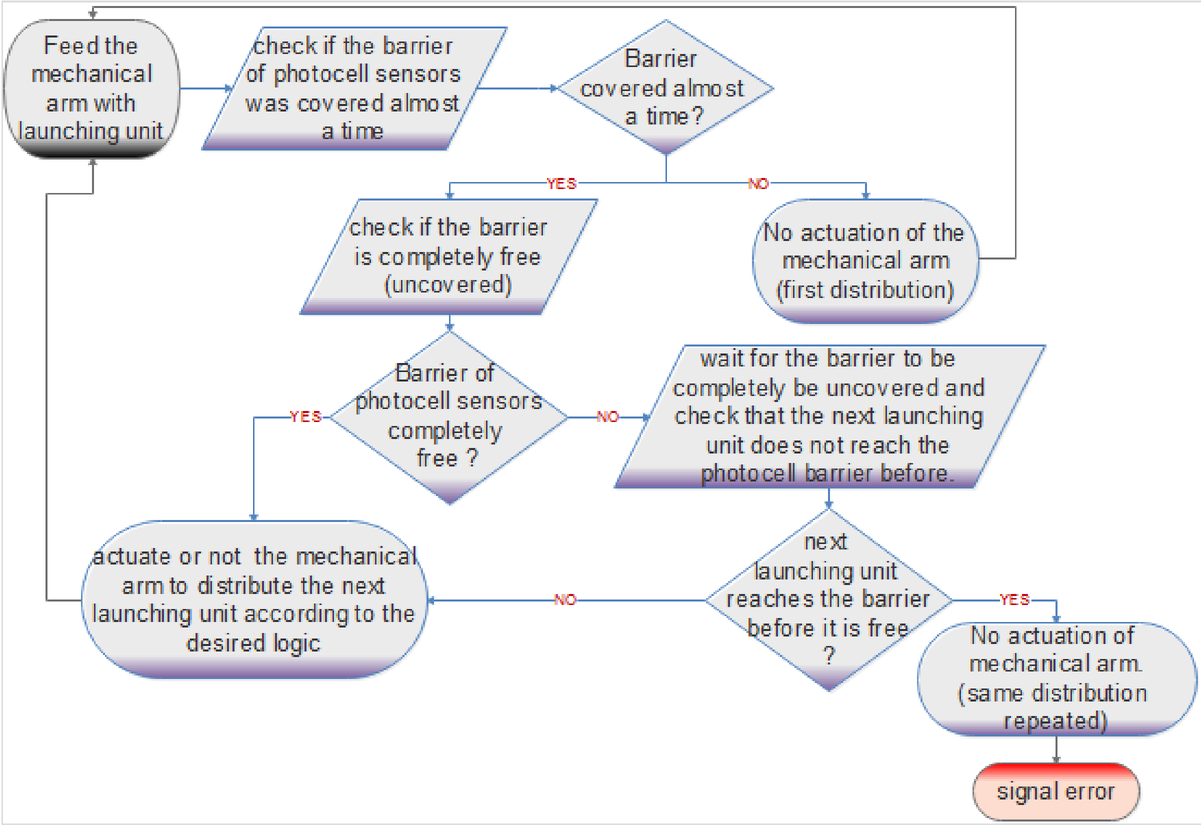
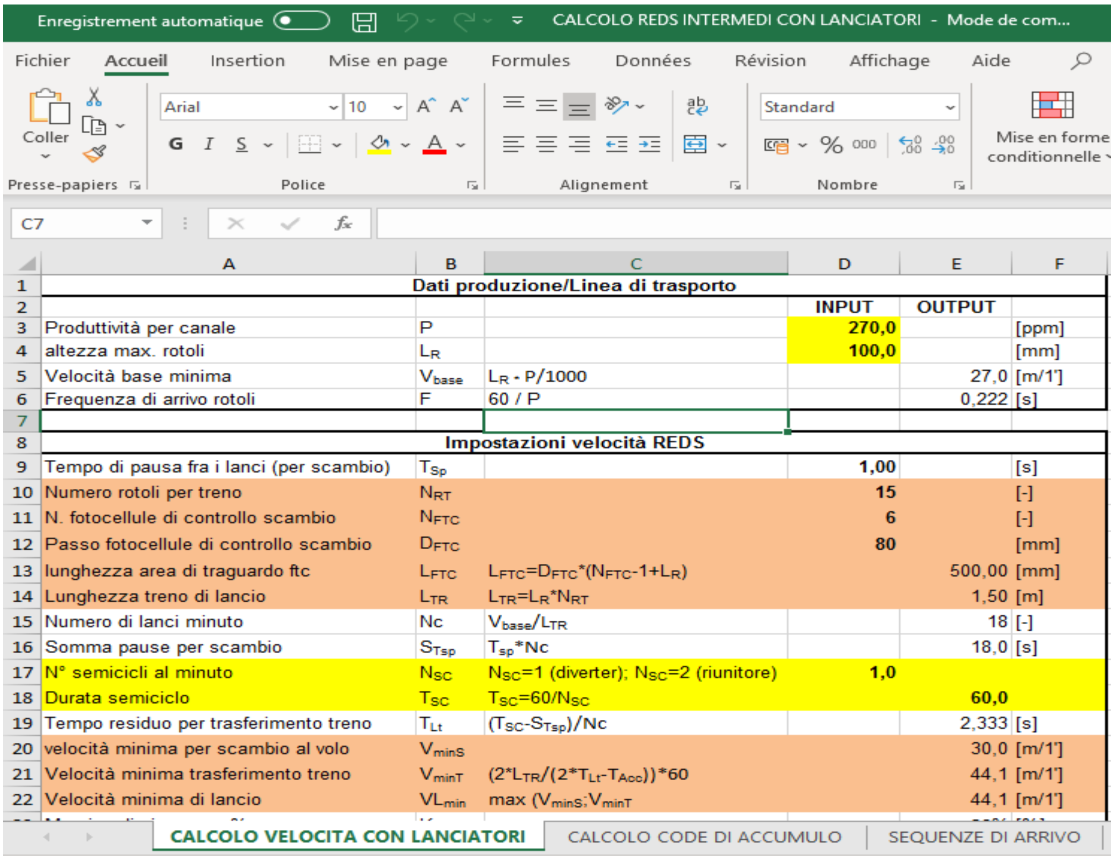


Figure 4.11: Flowchart to Distribute products

4.2.4 Spreadsheets

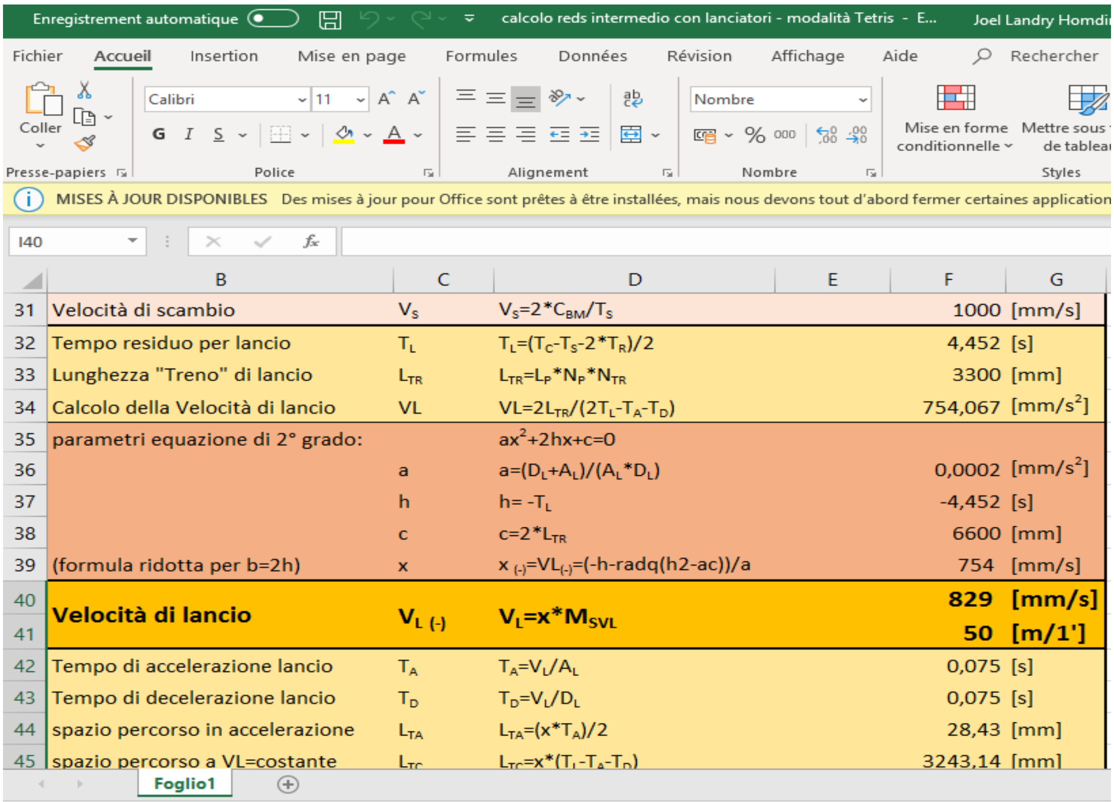
Once understood how the machine is built and describe its operation in previous sections, it is now possible to discuss the mathematical data on which the machine operates.

The company "Pulsar Engineering" has for this purpose spreadsheets allowing to obtain suitable data. These spreadsheets define data for working conditions and operating principles, and operates on variables such as speed, time, product length, productivity per channel ... These data were used in this project to make our model close to a real machine. Some examples of these spreadsheets are illustrated in figures 4.9, 4.10 and 4.11.



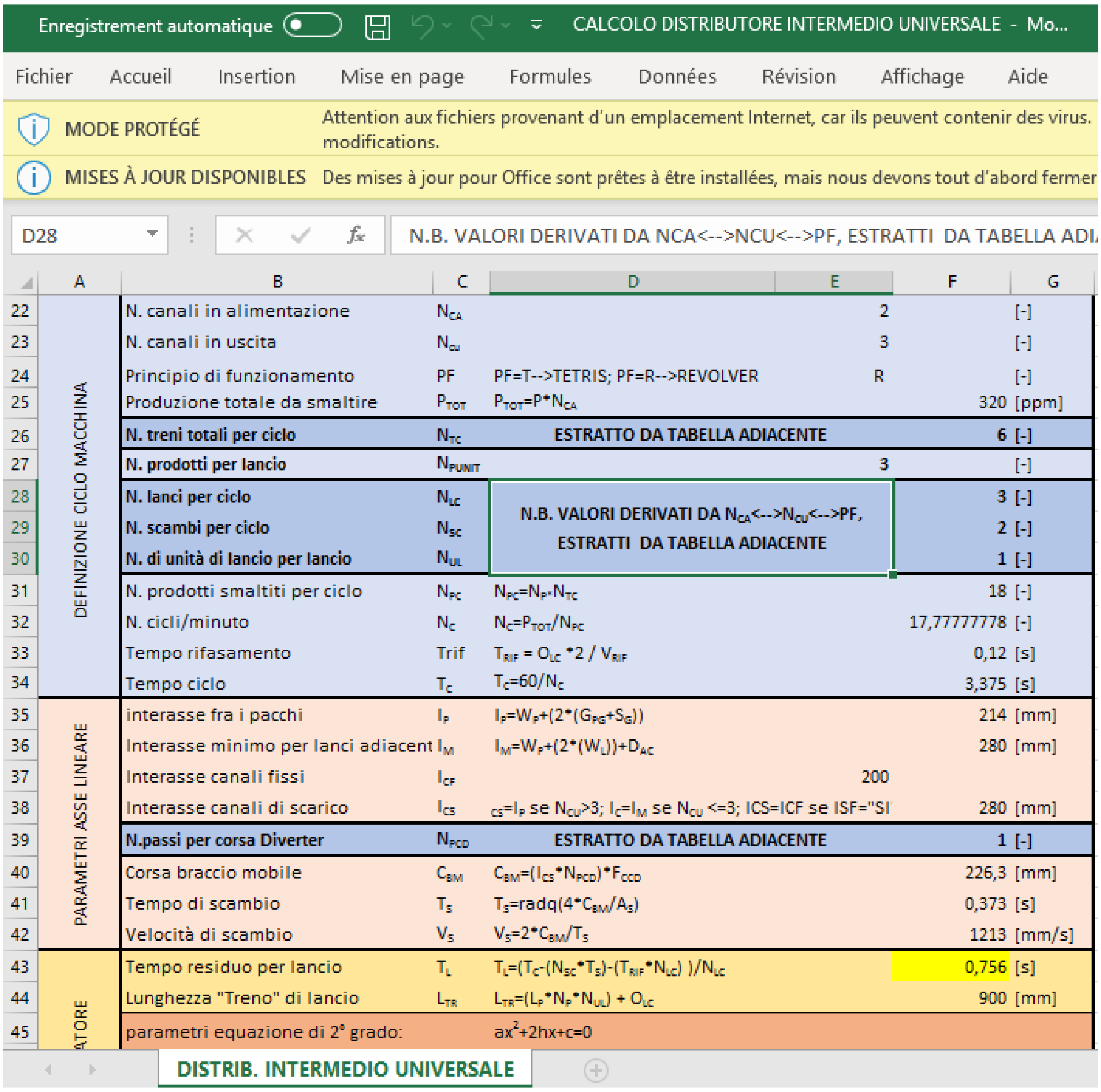
	A	B	C	D	E	F
1	Dati produzione/Linea di trasporto					
2				INPUT	OUTPUT	
3	Produttività per canale	P		270,0		[ppm]
4	altezza max. rotoli	L_R		100,0		[mm]
5	Velocità base minima	V_{base}	L_R - P/1000		27,0	[m/1']
6	Frequenza di arrivo rotoli	F	60 / P		0,222	[s]
7						
8	Impostazioni velocità REDS					
9	Tempo di pausa fra i lanci (per scambio)	T_{Sp}		1,00		[s]
10	Numero rotoli per treno	N_{RT}		15		[-]
11	N. fotocellule di controllo scambio	N_{FTC}		6		[-]
12	Passo fotocellule di controllo scambio	D_{FTC}		80		[mm]
13	lunghezza area di traguardo ftc	L_{FTC}	$L_{FTC}=D_{FTC}*(N_{FTC}-1+L_R)$		500,00	[mm]
14	Lunghezza treno di lancio	L_{TR}	$L_{TR}=L_R*N_{RT}$		1,50	[m]
15	Numero di lanci minuto	Nc	V_{base}/L_{TR}		18	[-]
16	Somma pause per scambio	S_{Tsp}	T_{sp}*Nc		18,0	[s]
17	N° semicicli al minuto	N_{SC}	N_{SC}=1 (diverter); N_{SC}=2 (riunitore)	1,0		
18	Durata semiciclo	T_{SC}	$T_{SC}=60/N_{SC}$		60,0	
19	Tempo residuo per trasferimento treno	T_{Lt}	$(T_{SC}-S_{Tsp})$/Nc		2,333	[s]
20	velocità minima per scambio al volo	V_{minS}			30,0	[m/1']
21	Velocità minima trasferimento treno	V_{minT}	$(2*L_{TR}/(2*T_{Lt}-T_{Acc}))*60$		44,1	[m/1']
22	Velocità minima di lancio	VL_{min}	max (V_{minS};V_{minT}		44,1	[m/1']

Figure 4.12: spreadsheet for a Diverter mode of REDS intermediates



	B	C	D	E	F	G
31	Velocità di scambio	V_S	$V_S=2*C_{BM}/T_S$		1000	[mm/s]
32	Tempo residuo per lancio	T_L	$T_L=(T_C-T_S-2*T_R)/2$		4,452	[s]
33	Lunghezza "Treno" di lancio	L_{TR}	$L_{TR}=L_P*N_P*N_{TR}$		3300	[mm]
34	Calcolo della Velocità di lancio	VL	$VL=2L_{TR}/(2T_L-T_A-T_D)$		754,067	[mm/s^2]
35	parametri equazione di 2° grado:		$ax^2+2hx+c=0$			
36		a	$a=(D_L+A_L)/(A_L*D_L)$		0,0002	[mm/s^2]
37		h	$h= -T_L$		-4,452	[s]
38		c	$c=2*L_{TR}$		6600	[mm]
39	(formula ridotta per b=2h)	x	$x_{(-)}=VL_{(-)}$=(-h-radq(h2-ac))/a		754	[mm/s]
40	**Velocità di lancio**	**$V_{L (-)}$**	**$V_L=x*M_{SVL}$**		**829**	**[mm/s]**
41					**50**	**[m/1']**
42	Tempo di accelerazione lancio	T_A	$T_A=V_L/A_L$		0,075	[s]
43	Tempo di decelerazione lancio	T_D	$T_D=V_L/D_L$		0,075	[s]
44	spazio percorso in accelerazione	L_{TA}	$L_{TA}=(x*T_A)/2$		28,43	[mm]
45	spazio percorso a VL=costante	L_{TC}	$L_{TC}=x*(T_L-T_A-T_D)$		3243,14	[mm]

Figure 4.13: spreadsheet for a combiner mode of REDS intermediates



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Fichier Accueil Insertion Mise en page Formules Données Révision Affichage Aide

MODE PROTÉGÉ Attention aux fichiers provenant d'un emplacement Internet, car ils peuvent contenir des virus. modifications.

MISES À JOUR DISPONIBLES Des mises à jour pour Office sont prêtes à être installées, mais nous devons tout d'abord fermer

D28 | N.B. VALORI DERIVATI DA NCA<-->NCU<-->PF, ESTRATTI DA TABELLA ADI...

	A	B	C	D	E	F	G
22	DEFINIZIONE CICLO MACCHINA	N. canali in alimentazione	N_{CA}		2		[-]
23		N. canali in uscita	N_{CU}		3		[-]
24		Principio di funzionamento	PF	PF=T-->TETRIS; PF=R-->REVOLVER	R		[-]
25		Produzione totale da smaltire	P_{TOT}	$P_{TOT}=P*N_{CA}$		320	[ppm]
26		**N. treni totali per ciclo**	N_{TC}	**ESTRATTO DA TABELLA ADIACENTE**		**6**	[-]
27		**N. prodotti per lancio**	N_{PUNIT}		3		[-]
28		**N. lanci per ciclo**	N_{LC}	**N.B. VALORI DERIVATI DA N_{CA}<-->N_{CU}<-->PF, ESTRATTI DA TABELLA ADIACENTE**		**3**	[-]
29		**N. scambi per ciclo**	N_{SC}			**2**	[-]
30		**N. di unità di lancio per lancio**	N_{UL}			**1**	[-]
31		N. prodotti smaltiti per ciclo	N_{PC}	$N_{PC}=N_P \cdot N_{TC}$		18	[-]
32		N. cicli/minuto	N_C	$N_C=P_{TOT}/N_{PC}$		17,77777778	[-]
33		Tempo rifasamento	Trif	$T_{RIF} = O_{LC} *2 / V_{RIF}$		0,12	[s]
34		Tempo ciclo	T_C	$T_C=60/N_C$		3,375	[s]
35	PARAMETRI ASSE LINEARE	interasse fra i pacchi	I_P	$I_P=W_P+(2*(G_{PG}+S_G))$		214	[mm]
36		Interasse minimo per lanci adiacent	I_M	$I_M=W_P+(2*(W_L))+D_{AC}$		280	[mm]
37		Interasse canali fissi	I_{CF}		200		
38		Interasse canali di scarico	I_{CS}	$_{CS}=I_P$ se $N_{CU}>3$; $I_C=I_M$ se $N_{CU}<=3$; ICS=ICF se ISF="SI		280	[mm]
39		**N.passi per corsa Diverter**	N_{PCD}	**ESTRATTO DA TABELLA ADIACENTE**		**1**	[-]
40		Corsa braccio mobile	C_{BM}	$C_{BM}=(I_{CS}*N_{PCD})*F_{CCD}$		226,3	[mm]
41		Tempo di scambio	T_S	T_S=radq(4*C_{BM}/A_S)		0,373	[s]
42		Velocità di scambio	V_S	$V_S=2*C_{BM}/T_S$		1213	[mm/s]
43	ATORE	Tempo residuo per lancio	T_L	$T_L=(T_C-(N_{SC}*T_S)-(T_{RIF}*N_{LC}))/N_{LC}$		0,756	[s]
44		Lunghezza "Treno" di lancio	L_{TR}	$L_{TR}=(L_P*N_P*N_{UL}) + O_{LC}$		900	[mm]
45		parametri equazione di 2° grado:		$ax^2+2hx+c=0$			

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Figure 4.14: spreadsheet for a general case (Diverter and combiner)

4.2.5 programming

In the previous sections, we have defined the configuration, the algorithm and the data necessary to obtain the model. This section discusses the programming methods and strategies used to obtain the final model.

The programming language used in the software plant simulation is called SimTalk. SimTalk is a kind of object programming language. The source codes are inserted into object Methods M (figure 4.12). These methods operate on a set of variables, tables and data.

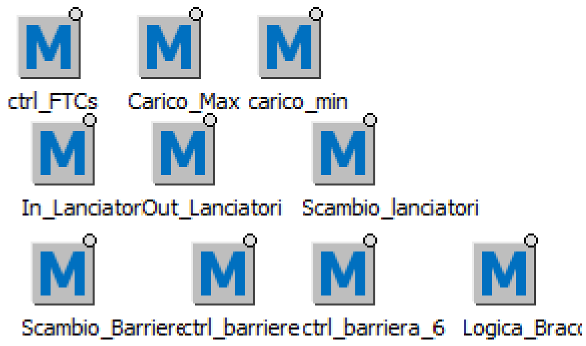

Figure 4.15: some Programming methods

Many methods have been used to obtain our model and the most important are:

- An initialization method: It makes it possible to define initial conditions and to impose initial values on the variables. It is reparable under the name "INIT".

- A method to the manage each sensor mentioned in section 4.2.2: these different methods are:

    - "carico_max" and “carico_min”: Respectively for the maximum and minimum load sensors

    - "In-lanciatori" and Out_lanciatori which respectively control the sensors at the entry (no-load starting sensor) and exit (rephaser sensor) of the launcher.

    - "crtl_barriere" and “ctrl_barriera_6" to manage the barrier of photocell sensors.

- A method that acts as a timer for all sensors called "ctrl_FTCs"

- Some methods related to the operating mode of the REDS (Diverter or Combiner) and to the operating strategy to be perform (Tetris or Revolver). They are: “Scambio_lanciatore”, “Scambio_barriere” and "Logica _Braccia".

Apart from these methods, others internal methods have been used to obtain the model.

The figures below show examples of codes written to obtain the model.

.libreria.machines.Diverter.init

```
var i:integer;


&ctrl_FTCs.methcall(1);   --INIT CTRL_FTCs (ricorsivo)
 Num_lancio_ctrl:=0;

--------------INIZIALIZZAZIONE NEI NASTRI IN INGRESSO-----------
for i:=1 to numero_canali_input_max loop

    str_to_obj(sprint(to_str(current),".Carico_max_",i)).Speed:=vr/60 ;
    str_to_obj(sprint(to_str(current),".Carico_min_",i)).speed:=Vr/60 ;
    str_to_obj(sprint(to_str(current),".Carico_min_",i)).tempo_min:=0;
    str_to_obj(sprint(to_str(current),".Carico_max_",i)).tempo_max:=0;
    str_to_obj(sprint(to_str(current),".Carico_min_",i)).S_min_coperto:=false;
    str_to_obj(sprint(to_str(current),".Carico_max_",i)).S_max_coperto:=false;

    str_to_obj(sprint(to_str(current),".lanciatore",i)).Speed:=0 ;
    str_to_obj(sprint(to_str(current),".lanciatore",i)).count_parts:=0 ;
    str_to_obj(sprint(to_str(current),".lanciatore",i)).num_lancio:=0 ;
    str_to_obj(sprint(to_str(current),".lanciatore",i)).num_ciclo:=0 ;
    str_to_obj(sprint(to_str(current),".lanciatore",i)).incremento_cicli:=0 ;
    str_to_obj(sprint(to_str(current),".lanciatore",i)).incremento_lanci:=0 ;

    str_to_obj(sprint(to_str(current),".BraccioREDS",i)).count_parts:=0 ;
    str_to_obj(sprint(to_str(current),".BraccioREDS",i)).Num_Ciclo:=0 ;
    str_to_obj(sprint(to_str(current),".BraccioREDS",i)).Num_Lancio:=0 ;
    str_to_obj(sprint(to_str(current),".BraccioREDS",i)).speed:=0 ;
    str_to_obj(sprint(to_str(current),".BraccioREDS",i)).Num_succ:=0 ;
next;
for i:=1 to max(tabella_max.ydim,tabella_min.ydim) loop

    tabella_min["STATO",i]:= void;
```

Figure 4.16: INIT method

.Models.Frame.Diverter.Carico_Max

```
param SensorID : integer, Front : boolean
    var oggetto:object;
    var lane:string;
    var tabella_pos:table; -- tabella in cui tenga traccia dei rotoli presenti
    var numero:integer;

    if Front then
        oggetto:=@;
        if oggetto/=VOID then
            lane:= strRcopy(obj_to_str(?),1);
            tabella_max["STATO",str_to_num(lane)]:= "PRESENZA";
            tabella_max["TEMPO",str_to_num(lane)]:= 0;
        end;

    else
        oggetto:=@;
        ?.contentslist(tabella_pos);
        tabella_pos.cursorx:=1;
        tabella_pos.cursory:=1;

        if tabella_pos.find(oggetto) then
            numero:=tabella_pos.cursory;
            if numero<tabella_pos.ydim then

                if (tabella_pos[2,numero] - tabella_pos[3,numero+1] ) >0 then

                    ----aggiorno tabella del tratto stato delle singole ftc canale per canale---
                    lane:= strRcopy(obj_to_str(?),1);
                    tabella_max["STATO",str_to_num(lane)]:= "ASSENZA";
                    tabella_max["TEMPO",str_to_num(lane)]:= 0;

                else
```

Figure 4.17: Method for maximum load sensor (Carico_max)

.Models.Frame.Diverter.Logica_Braccia

```
----LOGICA IN USCITA DELLE BRACCIA DEL REDS
        var num,Num_succ:integer;

if tipo=1 or tipo=3 or tipo=4 then
    num:= str_to_num (strRcopy(obj_to_str(?),1));

    if famiglia="A" or famiglia="B" or famiglia="C" or famiglia="D" or famiglia="E" or famiglia="LAN

        if modalità="DIVERTER" then -------DIVERTER FAMIGLIE B,C e D------

            if famiglia="A" then
                if num_lancio>=1 and Num_lancio<=numero_canali_output then
                    @.move(?.succ(Num_lancio));
                else
                    @.move(?.succ(ciclo-num_lancio+1));
                end

            elseif famiglia="B" then
                    if ( (Num_lancio>=1 and Num_lancio<=Numero_canali_output-num) or (Num_lancio>num
                        @.move(?.succ(num));
                    else
                        @.move(?.succ(num+1));
                    end

            elseif famiglia="C" then

                 num_succ:=tab_Succ_Fam_C_div_B[num,num_lancio];
                 @.move(?.succ(Num_succ));
```

Figure 4.18: Methods for the distribution logic of the mechanical arm

4.3 Results

The REDS intermediate model obtained shows very satisfactory results. We present some of these results in this section. The 3D model of the machine is represented in figure 4.16.

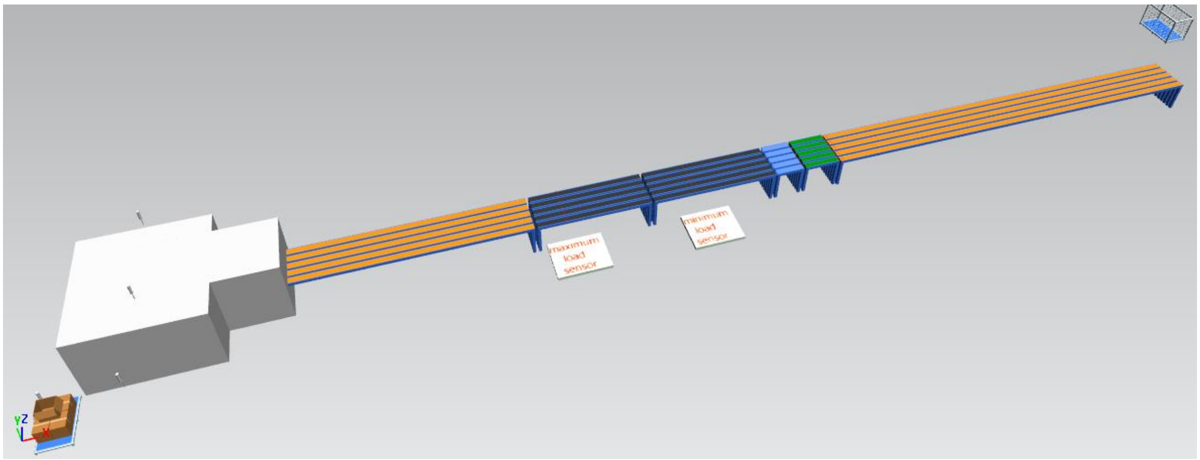

Figure 4.19: The 3D REDS intermediate model

We show the visualization in 3D for the cases of: Diverter_4x5_revolver, Diverter_4x5_TETRIS, Combiner_4x3_REVOLVER and Combiner_4x3_TETRIS.

- Diverter_4x5_Revolver

Figure 4.17 show a general 3D view of the diverter working in this configuration (Revolver strategy). We can note in these figures the distribution from 4 channels in input to 5 channels in output as expected. In figure 4.18 it is possible to appreciate the upstream accumulation queue. The machine consumes evenly on all conveyors as required by the revolver strategy. The distribution at the exit is exactly the one described in the section 3.6 (figure 4.19).

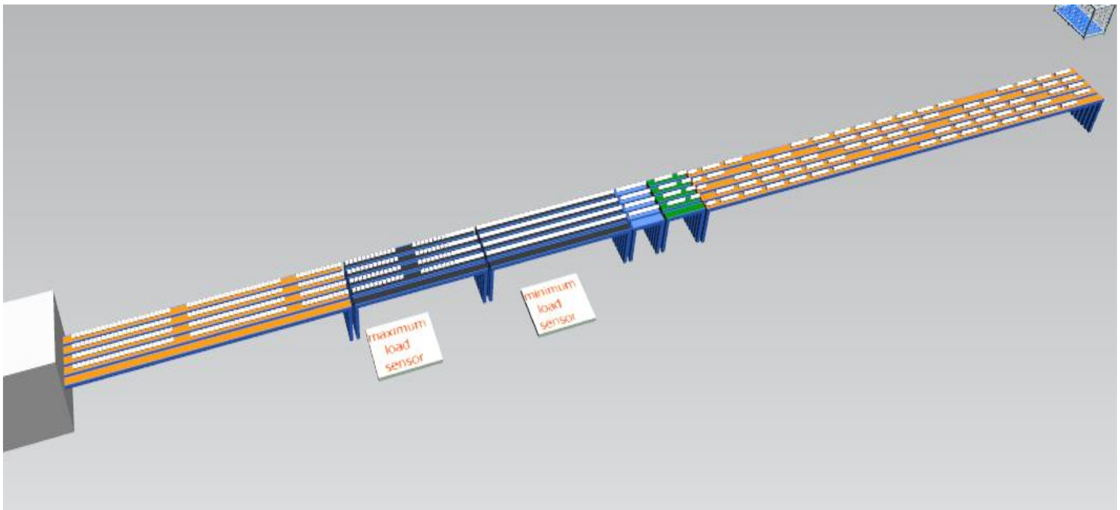

Figure 4.20: General 3D view of the Diverter_4x5_Revolver

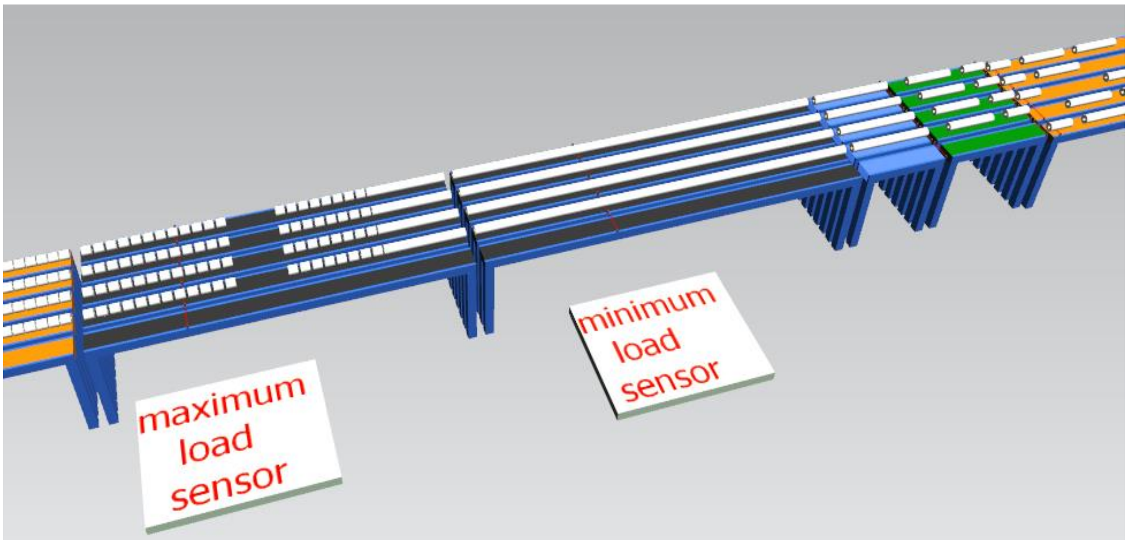

Figure 4.21: upstream accumulation queue of a Diverter_4x5_revolver

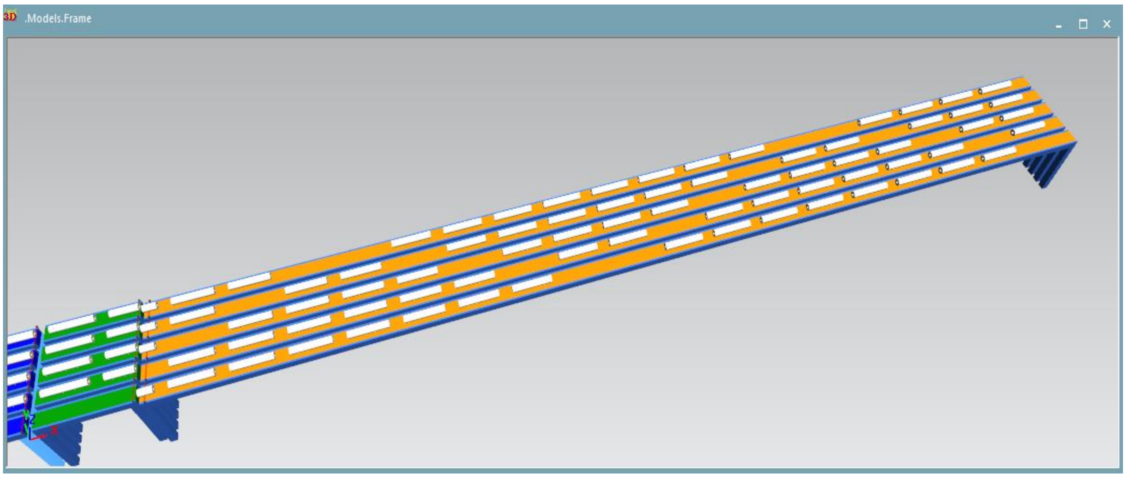

Figure 4.22: Distribution at the exit of a Diverter_4x5_revolver

- Diverter_4x5_TETRIS

As in the previous case, we can see in figures 4.20, 4.210 and 4.22 respectively in 3D, a general view, a view of the accumulation queues upstream the REDS and a view of the expected distribution (Tetris strategy). The upstream accumulation queue and the distribution at the exit of the REDS confirm the fact that the machine works with the Tetris strategy.

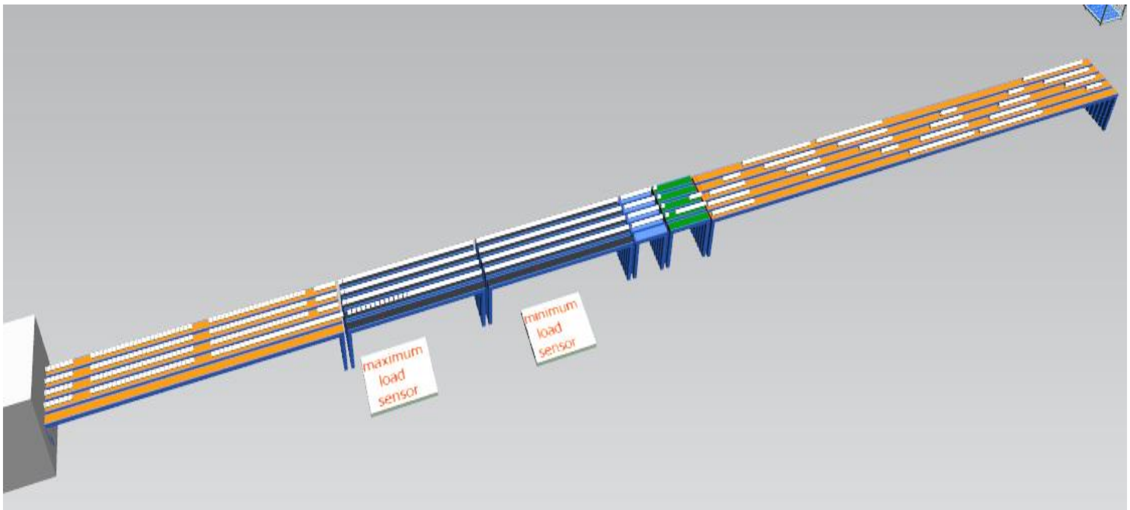

Figure 4.23: General 3D view of the Diverter_4x5_Tetris

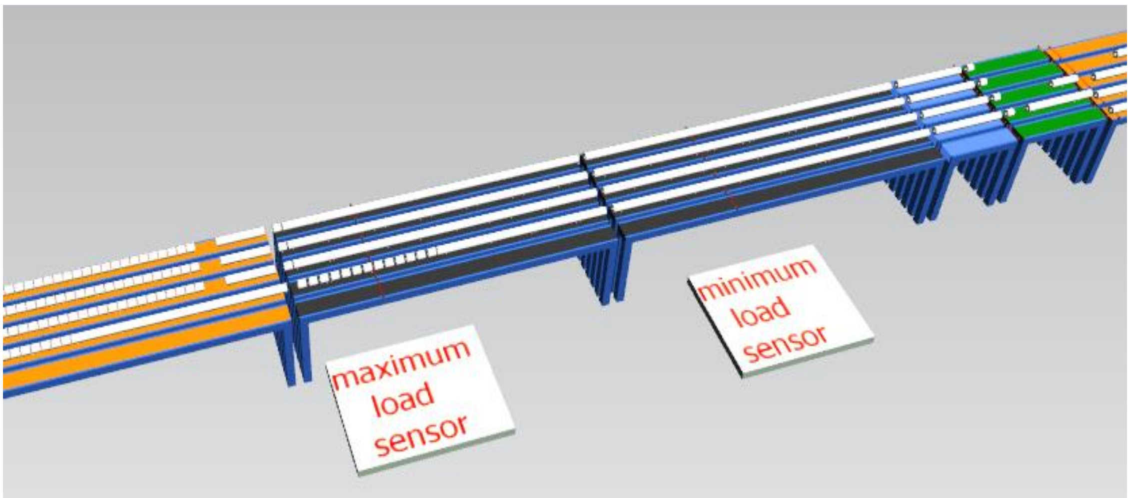

Figure 4.24: upstream accumulation queue of a Diverter_4x5_Tetris

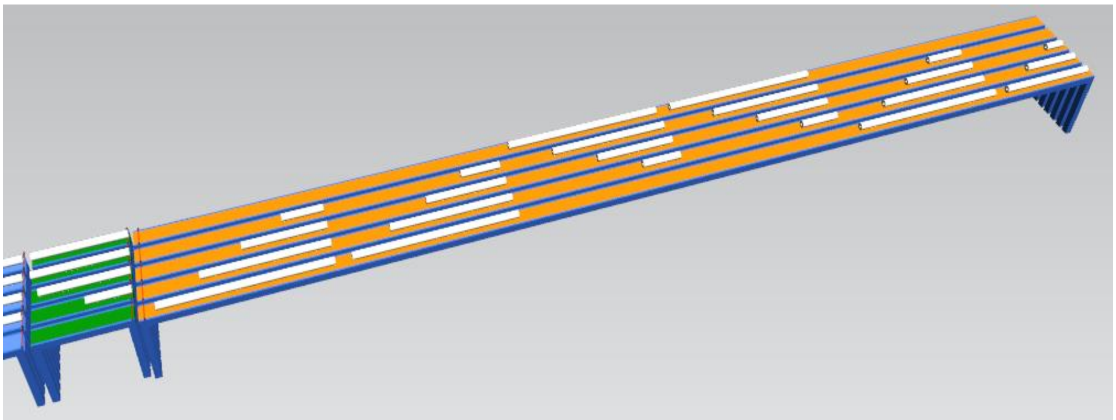

Figure 4.25: Distribution at the exit of a Diverter_4x5_Tetris

- Combiner_4x3_Revolver

Figures 4.23, 4.24 and 4.25 show the simulation in this configuration. We exactly obtained the expected results as described in section 3.6. In particular, the distribution is performed from 4 channels in input to 3 channels in output and the machine evenly consume the products from the desired conveyors.

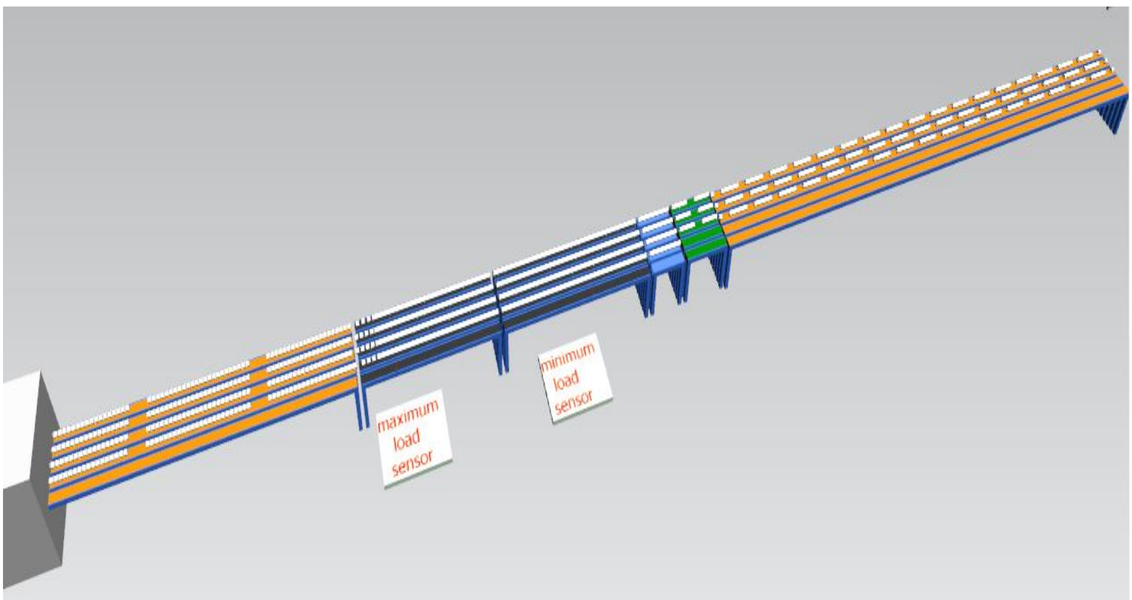

Figure 4.26: General 3D view of the Diverter_4x3_Revolver

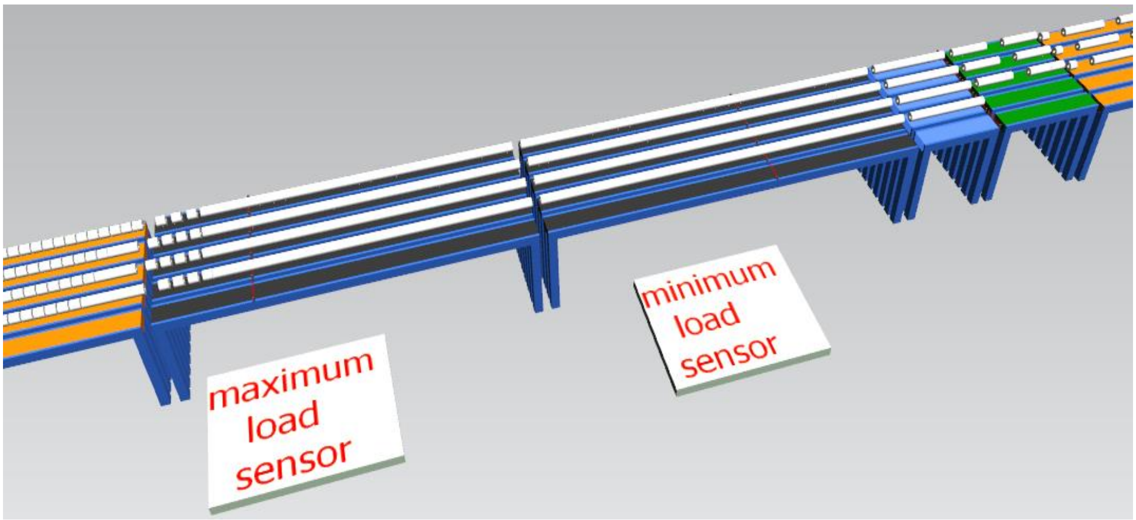

Figure 4.27: upstream accumulation queue of a Combiner_4x3_Revolver

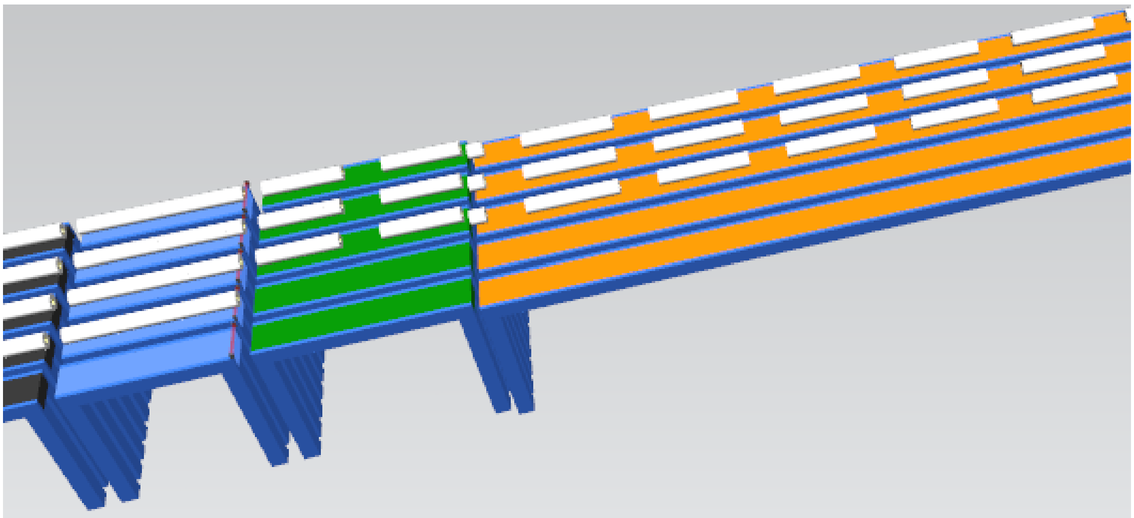

Figure 4.28: Distribution at the exit of a combiner_4x3_Revolver

- Combiner_4x3_TETRIS

We can observe in the figures above the simulation of the Tetris version of the previous combiner_4x3. The results obtained also satisfies our expectations defined in section 3.6.

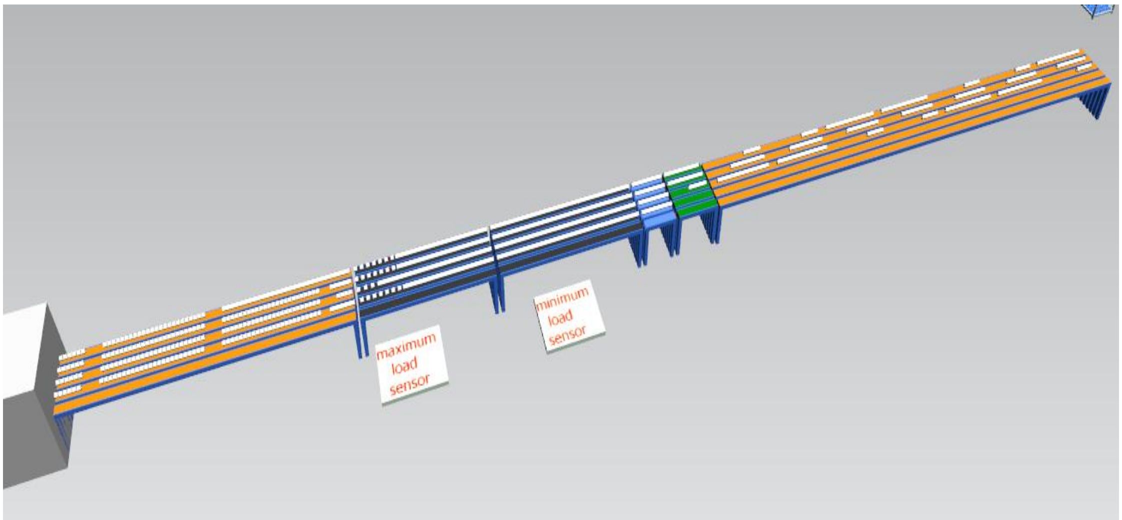

Figure 4.29: General 3D view of the Diverter_4x3_Tetris

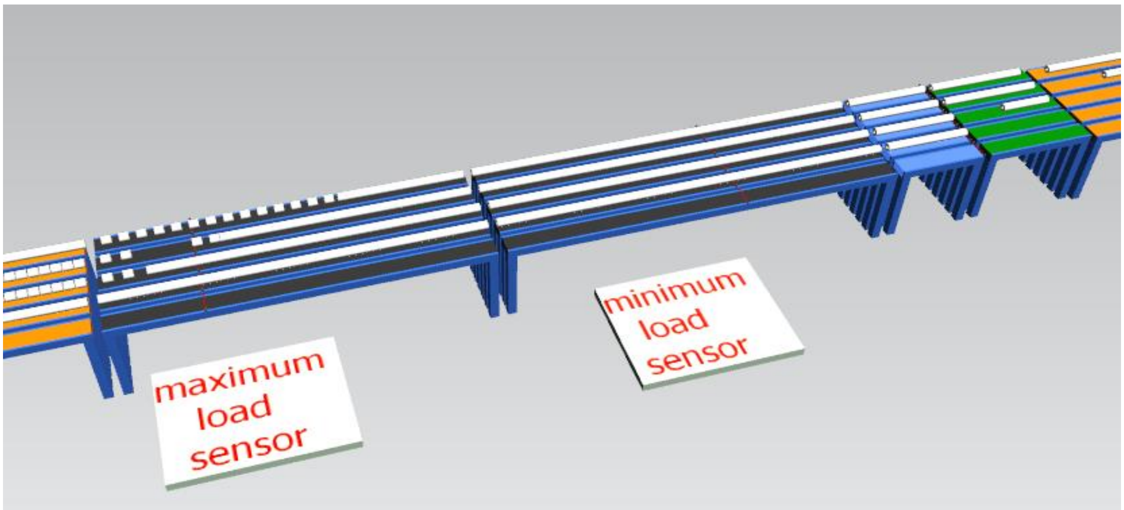

Figure 4.30: upstream accumulation queue of a Combiner_4x3_Tetris

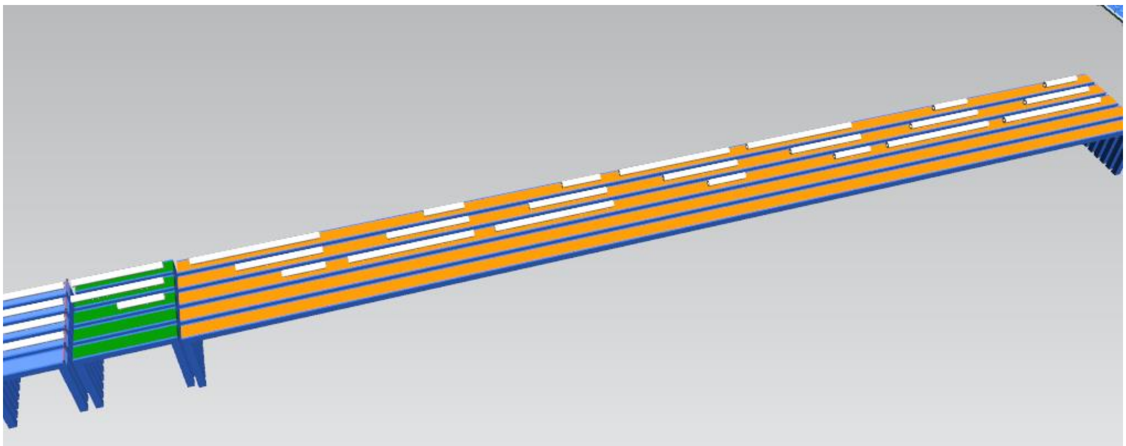

Figure 4.31: Distribution at the exit of a combiner_4x3_Tetris

In the following figures, we show some others simulation results.

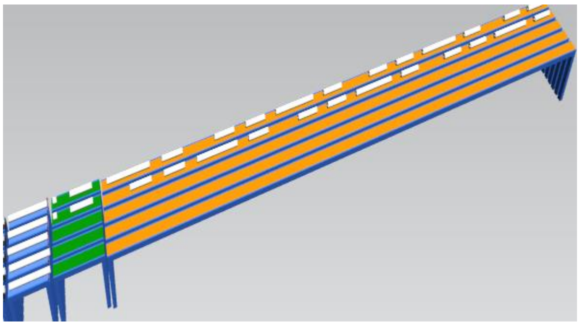

Figure 4.32: Combiner_5x2_Tetris

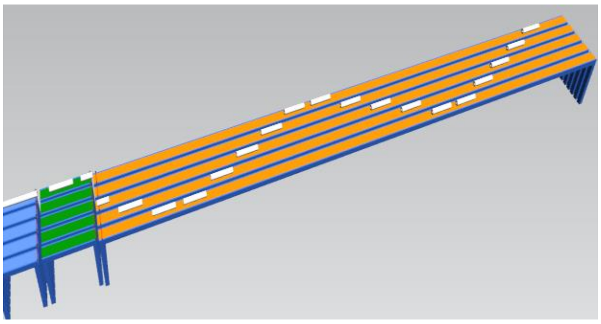

Figure 4.33: Diverter_1x5_Revolver

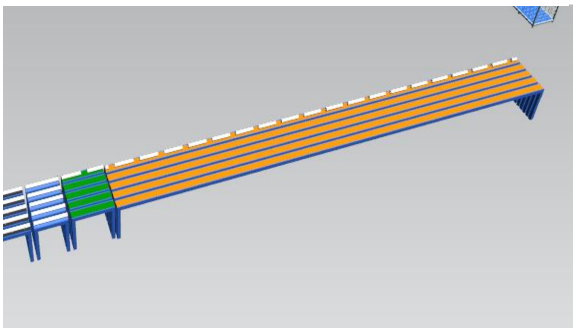

Figure 4.34: Combiner_5x1_revolver

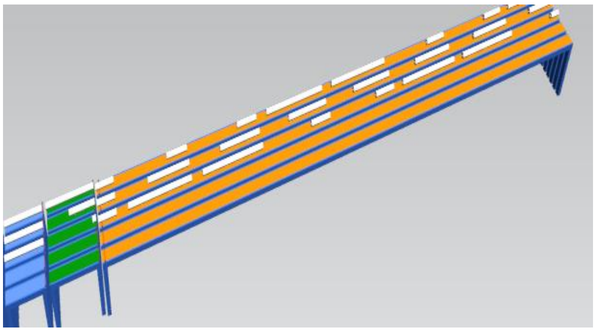

Figure 4.35: By-Pass_3x3_Tetris

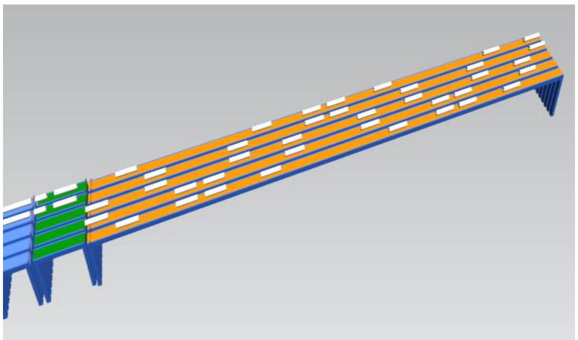

Figure 4.36: Diverter_2x5_Revolver

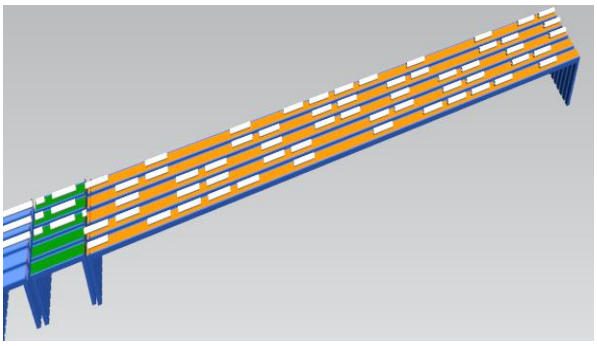

Figure 4.37: Diverter_3x5_revolver

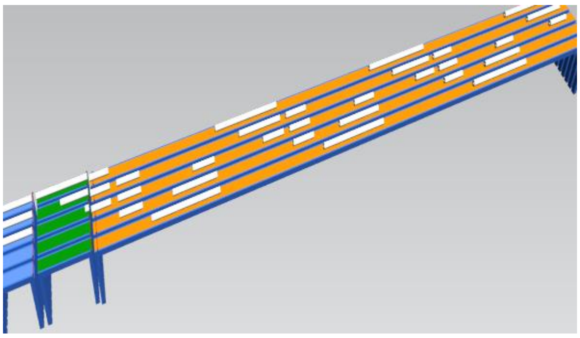

Figure 4.38: Diverter_3x5_Tetris

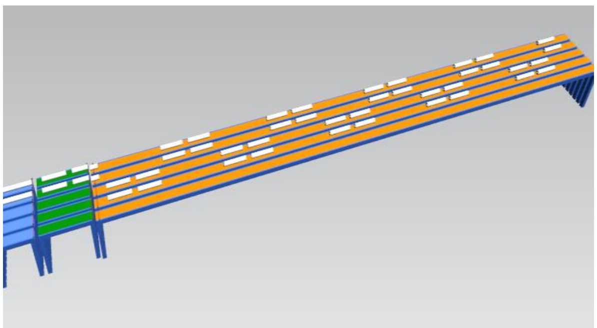

Figure 4.39: Diverter_2x4_Revolver

Mathematical Results

From the software, we can easily obtain some important mathematical results by using the statistics provide by the component called "Drain". In fact, the simulation can be done for a fixed time defined by the tool "EventController", and at the end of this time, the "drain" provide important statistics such as: The total throughput, the throughput per hour and per day, the working times…(figure 4.37)

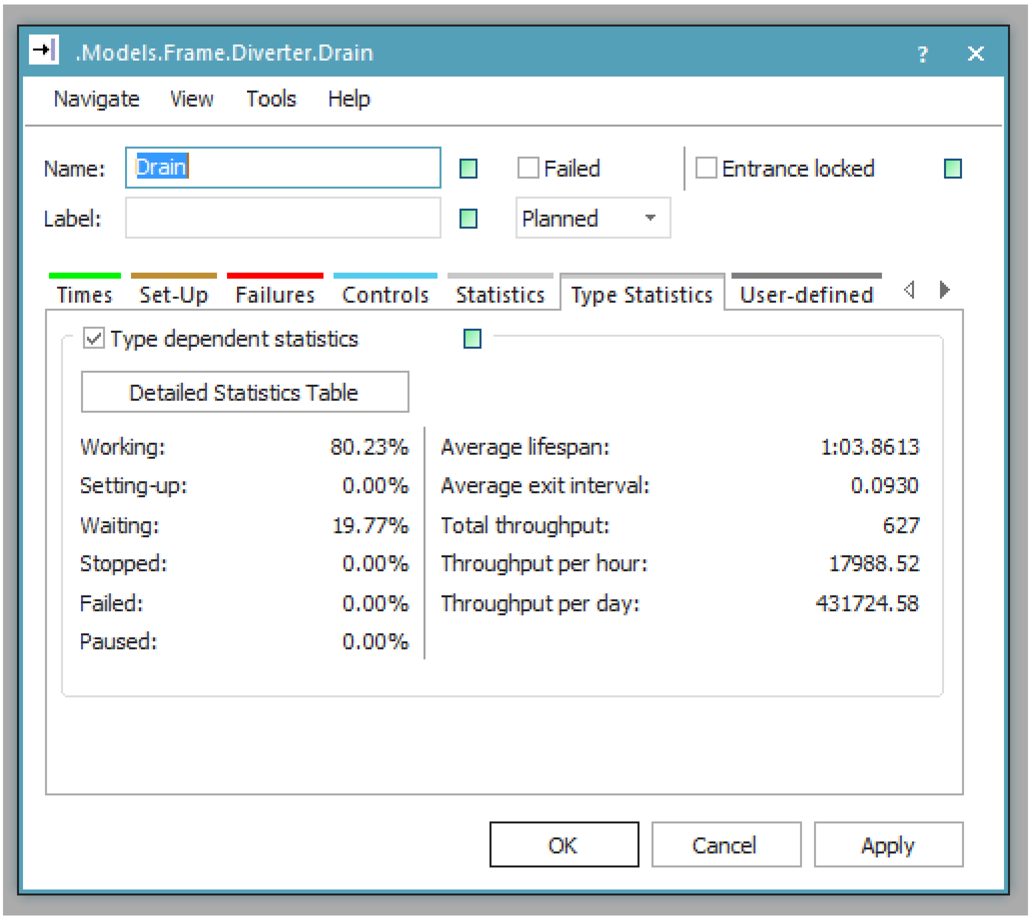

Figure 4.40: Drain statistics

A significant result of simulation is the calculation of the production efficiency. That is:

$$Efficiency = \frac{produced\ quantity}{production\ target\ quantity} * 100$$

Where:

Produced quantity = Quantity of products elaborated in simulation time.

Production target quantity= Expected quantity of products.

Note that for the case of interest, since we are dealing with a single machine without real interaction with another process machine, the efficiency is 100%.

5. Conclusion

5.1 Achievements

In this paper, a dynamic model of a REDS intermediate has been designed using the tool “Plant simulation “. The results obtained through the simulations allow us to conclude that the model obtained satisfies almost all the operating requirements of existing REDS INTERMEDIATE. This model allows to simulate many different types of REDS Intermediates and has a great flexibility of modification and adaptation according to the requirements of the user.

5.2 Future improvements

A future improvement could consider a model supporting the combination, in the same operating cycle, of two or more operating modes (Diverter, Combiner and By-pass). Another step could be to allow the switching in real time from a distribution strategy (Revolver, Tetris) to another. All these improvements would make it possible to adapt better to some working constraints.

Bibliography

- *[1] "Bilanciamento di line produttive per il tissue", Negrini Sara. (cited on pages 14,17,18,19,20 and all diagrams on pages 20-46)*

- *[2] "Simulazion del flusso di prodotti su una line di trasporto rotoli in condizioni di regime e in risposta ad eventi discreti" , Laura Bertoli. (cietd on pages 7-10)*

Thanks

Writing these sentences of thanks is the final touch of my thesis. I would like to say a few words of thanks to all the people who supported and helped me during this period.

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A special thought to my dad who will certainly be proud of me!

I would like to thank my dearest people, without whom I could never have achieved this goal. So, I thank my big family of friends. We have always supported each other, in good times and in bad times, during the labors and despair, in moments of joy and satisfaction. Thank you very much!

A heartfelt thanks to all!

Joel Landry Homdim Tchuenteu.