Glossary

spill	an unwanted situation where pellets are spilled inside the plant boundary
preventive barrier	a barrier that prevents a spill from occurring
mitigating barrier	a barrier that assures that the spill does not become a loss

Bow-Tie Model Template Instructions

For the use of this Bow-Tie model template, first and foremost a meticulous assessment of the plant must be carried out, following the Pellets Loss Risk Assessment guidance. As a result, all the macro-areas (MAs) should be identified – Figure A.1, as well as any critical points (CPs) that may be inside each one of these MAs.

Moreover, the data to feed the model must be available. For that purpose, a series of steps should be followed to ensure the proper function of the Bow-Tie model.

The Bow-Tie model is embedded in an *MS Excel®* workbook. The main worksheets are *Instructions*, which includes a list with the instructions to follow for the completion of the model and a table with the description of all the variables and parameters involved, as well as some acronyms; *Structure*, which the structure of the model is adjusted; *Inputs*, where all the measurements/estimations need to be charged; CP_i and MA_i, where the structure of the preventive/mitigating barriers is defined; and *Analysis*, where a summary of the MAs and plant performance takes place. The remaining worksheet only contains some functional reference tables, but they do not require any input from the user nor show any result.

Once the MAs have been defined, and eventually, CPs have been designated, the corresponding measurements/estimations on the pellet spills must be taken. Afterwards, a decision must take place in each MA, regarding if the CP-approach or the MA-approach is going to be followed. In the case that in the MA all spills are associated with a CP, the CP-approach can be implemented; otherwise, the MA should be pursued.

One of the advantages of the model is the relatively reduced number of inputs required. To make it easy, all the cells that require input from the user contain a hyphen "-" in the default workbook. Although, all the cells that do not require input are blocked to prevent undesired changes. In case that is necessary to introduce changes, the password to unlock the cells is *ocs* (in MS Excel® Review > Protect > Unlock Protect).

The model inputs can be sorted out into two general categories: measurement inputs and model structure/parameters. The first one is the set of measurements obtained from the plant, the second changes the way in which the model is structured and the information is processed; i.e., the disposition of the CPs and MAs, the preventive and mitigating barriers, as well as the evaluation of the efficiency of each barrier.

The measurements inputs only require the quantity of the **Spill without Barrier** [Kg/time] and the **Throughput Measurement** [Kg/time] – i.e., the streaming throughput of material at the measurement point – of the processed material at that specific critical point/macro area. In case the spills without a barrier are known to be in between a value range, it is advised to only use the maximum value, as this corresponds to a worst-case scenario. For each of these measurements, the sampling time frame can be adjusted separately, and then the amount of the measurement will be annualized automatically.

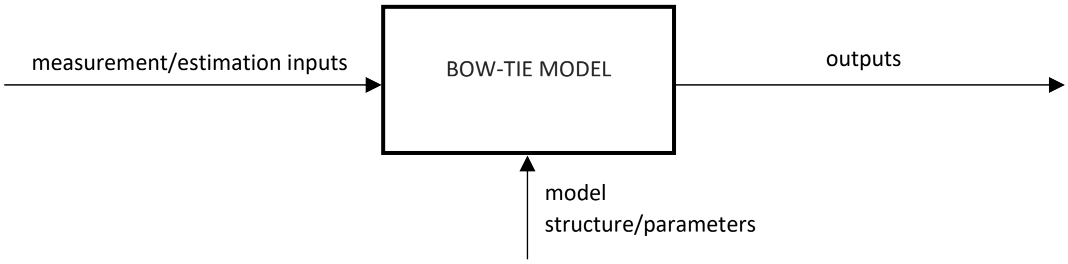


Figure 1. Bow-Tie model inputs/outputs.

The other class of inputs is regarding the structure of the model. There are spreadsheets assigned to each MA. In case a CP-approach is followed, there are spreadsheets under the name *CP_1*, *CP_2*, …, *CP_n*; where the information must be filled in. Elseways, in the case of an MA-approach, the spreadsheets to fill are under the names *MA_1*, *MA_2*, …, *MA_n*.

In the CP/MA spreadsheets, the preventive and mitigating barriers must be selected. These barriers can be placed in series or parallel disposition, accordingly as they are disposed of in the plant.

In the first worksheet, Instructions, the following list of instructions is found. Each of the numbers associated with each step is also placed throughout the document to show where that action must take place. Moreover, next to each number there is a reference to the worksheet where the action is required.

BOW-TIE MODEL

Operation Clean Sweep®

INSTRUCTIONS

	Worksheet	
①	**Structure**	Assign the number of Macro Areas (MA).
②	**Structure**	Assign the type of Approach (*CP_approach* or *MA_approach*), and the number of Critical Points (CP) for each Macro Area (MA).
③	**Structure**	Press the START MODEL button. If a mistake happens, press the RESET STRUCTURE button and repeat the previous steps. In case it is necessary, the button UNFOLD displays all the Worksheets contained in the Workbook, while the button CLEAR DATA does the same and also clears all inputs.
④	**Inputs**	Insert the value of the total annual Thoughput of the Plant. In this document, all the cells that require a value input show "-" in the default template.
⑤	**Inputs**	Define each Macro Area (MA).
⑥	**Inputs**	Define the Critical Points (CP) in the case of Macro Areas with critical point approach - *CP_approach* .
⑦	**Inputs**	Insert the values for "Time", "Spill without Barrier", and "Throughput Measurement".
⑧	**CP#** or **MA#**	Define the number of "Barriers in Series" and "Barriers in Parallel" for both, the preventive and mitigating barriers. Then press the button CREATE BARRIERS.
⑨	**CP#** or **MA#**	Define the barriers for each Critical Point in each of the Macro Areas. Then, for each of the barriers, assign a value [1-3] for the dependability (D), reliability (R), performance capacity (P), and effectiveness (E).
⑩	**CP#** or **MA#**	Insert a value for the Main MA Factor [0-1], which determines the fraction of pellets facing the Mitigation Barriers and the fraction going to the Periferic Areas (PA).

Figure 2. Capture from worksheet *Instructions*. Steps to follow throughout the workbook.

Likewise, there is a table including all the variables and acronyms involved – Figure 2.

STEP 1-3

First, the structure of the model needs to be adapted to every particular case – Figure 4. In the worksheet *Structure* – following the numbered steps 1-3; the number of Macro Areas must be defined, and after that, the type of approach, number of CP per MA, the maximum number of preventive barriers in series, and the maximum number of mitigating barriers in series. Once this data is charged, press the START STRUCTURE button.

This operation reduces and adjusts the whole structure of the model to the plant in question, and enables a series of tables to place further data.

An important feature throughout the model is that every cell that requires input, in the original file shows a hyphen, "-". This way it is easily recognizable. Also, the worksheets or table headers linked to a Macro Area where the critical point approach is followed are colored in orange; while the ones where the macro area approach is followed are colored in yellow.

REFERENCES		
Variable	**Description**	**Observation**
CP	Critical Point	
MA	Macro Area	
T	Throughput	Total amount of processed material
AS	Annual Spill	Annual Spill without any barriers
SP	Spill Probability	
SPB	Spill Probability after Barriers (preventive barriers)	
	The asterisk as a supraindex means that the factor corresponds to the Macro Area approach.	
SQ_i	Spills after preventive barriers that occur in the Main Macro Area or Periferic Areas.	
SB	Spill after Barriers (preventive barriers)	
LP	Loss Probability	
LOSS	Loss (after preventive and mitigating barriers)	
PA	Periferic Areas	Includes less accesible areas
PA factor	Fraction of the spills after preventive barriers that occur in Periferic Areas	
Main MA factor	Fraction of the spills after preventive barriers that occur in the Main Macro Area	

Figure 3. Table with references and nomenclatures in the worksheet *Instructions*.

MODEL STRUCTURE

Number of Macro Areas (MA)	-
	①

START MODEL ③ RESET STRUCTURE

②	Approach	Number of CP per MA [(1)]
MA 1	-	
MA 2	-	
MA 3	-	
MA 4	-	
MA 5	-	
MA 6	-	
MA 7	-	
MA 8	-	
MA 9	-	
MA 10	-	

Note 1: if "MA_approach" is selected for a Macro Area MA#, then the "Number of CP per MA" must be set to 1.

PROTECT UNPROTECT

Figure 3. Capture from worksheet *Structure*.

Button	Description
START MODEL	Creates and displays all the necesary worksheets and tables to apply the model.
RESET STRUCTURE	Resets the structure of the model as the default.
UNFOLD	Shows the full structure of the whole model.
CLEAR DATA	Resets and Deletes all input data.
PROTECT	Protects all the worksheets, so all the locked cells in the workbook remain protected against changes.
UNPROTECT	Unprotects all the spreadsheets, so all the locked cells in the workbook can be changed.

Figure 4. Capture from worksheet *Structure*. Available buttons for actions.

In case any of these parameters need to be changed, press the RESET STRUCTURE button and repeat steps 1-3.

As the workbook is protected by default in all the cells that do not require an input, two buttons are placed here: PROTECT and UNPROTECT, which lift the protection or place it again, respectively, leaving the possibility of altering the model. Moreover, the button FULL STRUCTURE shows the entire model without restrictions; and the button CLEAR DATA not only executes the same functions as FULL STRUCTURE but also clears all inputs. Nonetheless, in normal use of the Bow-Tie model, the buttons to be used are START STRUCTURE and RESET STRUCTURE.

STEPS 4-7

In the worksheet *Inputs*, steps 4-6 must be followed. For step 4, the value for the total annual Throughput of the Plant must be charged. Afterwards, for steps 5-6, the Macro Area and each one of its critical points – only in the case of the CP-approach – must be defined from a deployable list.

Throughput Plant [Kg/year]

④ -

Figure 5. Capture from worksheet *Inputs*.

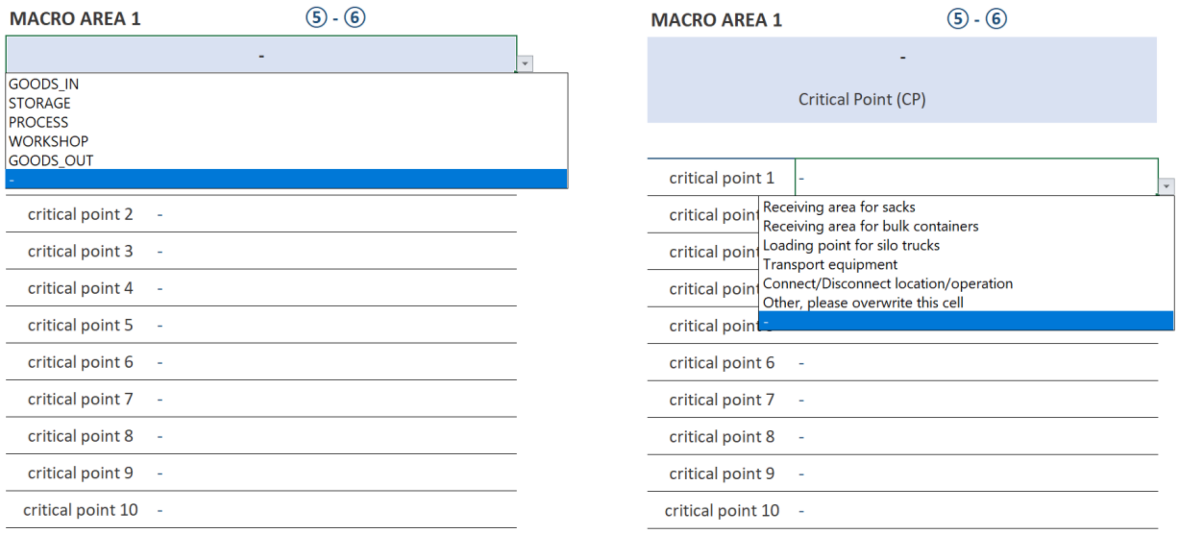


Figure 6. Capture from worksheet *Inputs*. Macro Area and critical points definition.

In Table 1, a list of default options for Macro Areas and Critical Points. In case the necessary options are not included, these lists can be modified to suit a particular plant. For that purpose, press the FULL STRUCTURE button in the worksheet Structure, then the UNPROTECT button, and finally direct to the worksheet *label*, where it is possible to modify the lists.

In the next step, the values for **Time**, **Spill without Barrier**, and **Throughput Measurement** must be provided in each Macro Area. Notice that the cells that require an input, initially show a hyphen, "-". The remaining factors in the table are calculated automatically; i.e., Throughput Annual (**AT**), Annual Spill (**AS**), and **SP**.

Table 1. List of available MAs and CPs for each of them.

Goods In

receiving area for sacks, *receiving area for bulk containers*, *loading point for silo trucks*, *transport equipment*, *connect/disconnect location/operation*.

Storage

handling of sacks, handling *of bulk containers*, *silo area (to be specified)*, *outgoing warehouse*, *conveying lines and couplings*, *goods dispatch/loading ramp*.

Process

feeding points, *sampling area*, *shredders*, *mixing units*, *internal recovery unit.*

Workshop

cutting, *drilling.*

Goods Out

handling of sacks, *handling of bulk containers*, *trucks loading/unloading*.

Off-Site Activities

cutting

⑦ *data input*

GOODS_IN					
Time [days]	Spill without barrier - MAX [kg/time]	Throughput Measurement [Kg/time]	Throughput Annual (AT) [Kg/year]	Annual Spill (AS) [Kg/year]	SP
-	-	-	-		
-	-	-	-		
-	-	-	-		
-	-	-	-		
-	-	-	-		
-	-	-	-		
-	-	-	-		
-	-	-	-		
-	-	-	-		
-	-	-	-		

⑦ *macro area approach*

GOODS_IN					
Time [days]	Spill without barrier - MAX [kg/time]	Throughput Measurement [Kg/time]	Throughput Annual (AT) [Kg/year]	Annual Spill (AS) [Kg/year]	SP*

Figure 7. Capture from worksheet *Inputs*. Spills quantities and probabilities.

Once all these inputs are provided, all the data concerning the spills is already in place. What remains is the definition of the preventive and mitigating barriers which can prevent spills from becoming losses.

STEPS 8-10

These steps take place in each one of the worksheets concerning each of the Macro Areas. Depending on if a certain Macro Area will be approached with the *CP approach* or the *MA approach*, the corresponding worksheet will be named as *CP#* or *MA#*, respectively. In these worksheets, the key element is the definition of the preventive and mitigating barriers. For the first ones, these can be placed one after the other in series, or they can be in parallel chains of barriers, according to the specifications made in the worksheet *Structure*. For each barrier, there is a table like the one shown in Figure 8.

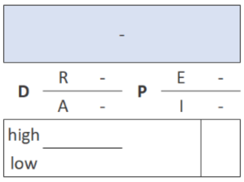


Figure 8. Capture from the worksheet CP# or MA#. Table to define a preventive/mitigating barrier.

The top of the table deploys a list where the barrier is set up. The list of preventive/mitigating barriers includes:

Table 2. List of the available preventive and mitigating barriers.

Preventive Barriers
collection trays, pellet/flake/powder disposal cans, retention trays (dry or wet), seals (on transfer equipment), buckets, outfitting forklifts with a clean-up kit, tools cleaning (shovel, vacuum cleaner, etc.), sumo gloves (forklift equipment), procedure for handling octabins, and procedure for handling sacks.

Mitigating Barriers

tools cleaning (shovel, vacuum cleaner, etc.), *cleaning schedule and monitoring system*, *drain covers*, *surface skimmers or vacuum system*, *dust collection equipment or filters*, *water separation filter*, *ventilation filters*.

Thereafter, once the barriers are in place, a series of coefficients must be defined regarding their properties, providing a quick assessment of the dependability and performance capability of the barrier. The parameters in question are, in the case of dependability (D), reliability (R), and availability (A); and for the performance capacity, effectiveness (E), and independence (I), respectively. For each one of these parameters, a set of coefficients {1,2,3} are available. The criteria to be followed in assigning each of these parameters is:

- The **reliability** (R) measures the failure rate of a barrier to performing its intended task. This is can be classified as the total number of failures divided by the total uptime of the barrier. The reliability is given a score of 1 when below 89%, a score of 2 when comprised between 89 and 99%, and a score of 3 when above 99%.
- The **availability** (A) measures the total uptime of the barrier divided by total downtime to get the percentage of available functional hours (Mean Time to Repair (MTTR) [hours] + Mean Time Between Repairs (MTBR) [hours], divided by MTBR). The availability is given a score of 1 when below 89%, a score of 2 when comprised between 89 and 99%, and a score of 3 when above 99%.
- The **effectiveness** (E) defines the ability of a barrier to avoid pellets spilled or lost passing through it. Hardware (i.e., filters) can be defined by the product specification (i.e., filter efficiency). The effectiveness is given a score of 1 when below 70%, a score of 2 when comprised between 70 and 90 %, and a score of 3 when above 90%.
- The **independence** (I) defines the promptness and the certainty of the barrier intervention: 1 – manually activated and executed; 2 – manually activated, automatically executed; 3 – automatically activated and executed.

Then, a series of calculations are executed based on the information provided. This includes the *Spill after Barriers* (**SB**), the *Spill Probability after Barriers* (**SPB**), and after them, a *Reduction Factor* label is calculated as an evaluation score for the set of preventive barriers put in place.

At this point, the last input demanded by the model is the *Main MA Factor*, which determines the fraction of spills that occur in the main parts of the MA, making the distinction from the *Peripheric Areas* (PA). Once the spills are split into their respective area, the mitigation barriers must be defined, with their respective parameters. After that, the *Loss* of pellets, *Loss Probability* (**LP**), and a *MA reduction factor* are obtained.

Finally, after feeding all the inputs to the model, a series of results emerge from the model. For instance, in every CP# and/or MP# worksheet, after the preventive barriers, there are the Spills Probability after Barriers (**SPB**), the Spills after Barrier (**SP**) – both expressing a minimum and maximum estimation, and the Macro Area reduction factor after the mitigating barriers.

A last set of inputs must be provided, these are the **MA Spilled Quantity** $\mathbf{SQ_i}$ and the **PA Spilled Quantity** $\mathbf{SQ_i}$. These factors determine the proportion of the spills that go through each line of mitigating barriers in series at the Main Macro Area and the Peripheric Areas, respectively – Figure 9.

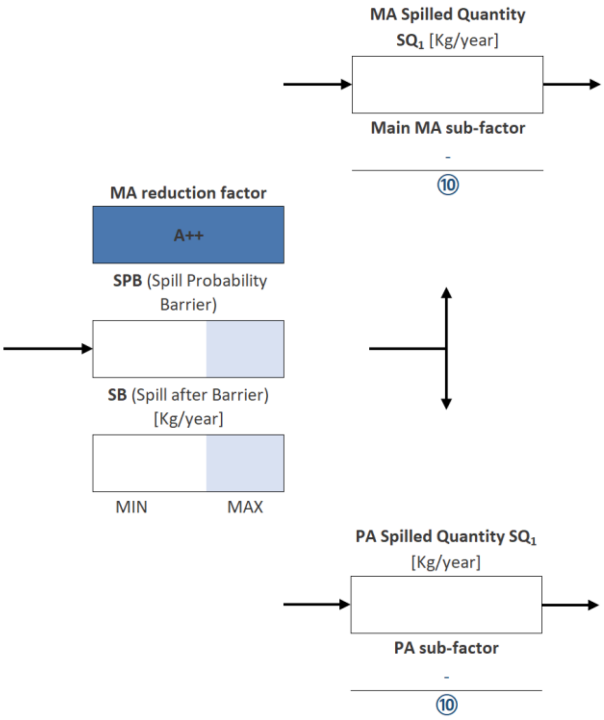
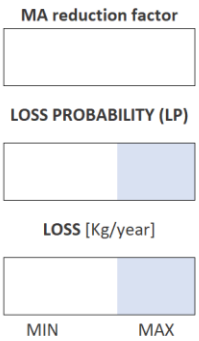


Figure 9. Capture from the worksheet CP# or MA#. Results table after preventive barriers.

Additionally, after the mitigating barriers, their evaluation and the estimated losses are shown in Figure 11. Here, the Loss Probability (**LP**) and **LOSS** – both expressing a minimum and maximum estimation and MA reduction factor after preventive and mitigating barriers are displayed.



Reduction Factor	Label
40%	F
50%	E
60%	D
70%	C
80%	B
90%	A
95%	A+
99%	A++

Expressed as Risk of Pellet Loss. The reduction label expresses the level of reduction on the pellet loss that occurs without barriers.

References			
D	**dependability**	P	**performance capacity**
R	reliability	E	effectiveness
A	availability	I	independency

Note: to cancel a preventive/mitigating barrier, please place on its corresponding selection list cell and press "delete".

Figure 11. Capture from the worksheet CP# or MA#. Results table after mitigating barriers.

The reduction factor is represented by a label linked to the percentage of spills captured.

Besides these partial results in each Macro Area, the main results are condensed in tables located in the worksheet *Inputs*, next to the values provided for the spills – Figure 12. If the CP-approach is followed, results appear as **SB** and **LOSS**; otherwise, if the MA approach is followed, results appear as **SB*** and **LOSS***.

RESULTS ANALYSIS - MACRO AREA 1											
SPB	SPB*	LP	LP*	SB		LOSS		SB*		LOSS*	
(max)	(max)	(max)	(max)	[Kg/year]		[Kg/year]		[Kg/year]		[Kg/year]	
				MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX

Figure 12. Capture from the worksheet *Inputs*. Results Analysis table.

Lastly, all the results for all the Macro Areas are condensed in the worksheet Analysis. These tables include a summary of the most important estimations the model provides, i.e., the annual spills (**AS**) per Macro Area, the Spill Probability after Barriers (**SPB**), the Loss Probability (**LP**), the Spills after Barriers (**SB**). Moreover, the last table calculates the most important factors to evaluate the performance of the whole plant in relation to the pellet losses, as is the case with the relationship between the total spills and the throughput of the plant (**AS / T**) and the total amount of pellet loss per unit of throughput (**LOSS / T**).

OVERALL RESULTS ANALYSIS							
Macro Area	**Approach**	**Annual Spill (AS)** [Kg/year]	**SPB / SPB***	**Overall SPB Overall SPB***	**LP / LP***	**SB / SB*** [Kg/year]	**Overall LP Overall LP***
MA 1	-						
MA 2	-						
MA 3	-						
MA 4	-						
MA 5	-						
Plant							

Figure 13. Capture from the worksheet *Analysis*. Overall Results Analysis table.

MA RESULTS ANALYSIS			
SB / SB*		**LOSS / LOSS***	
[Kg/year]		[Kg/year]	
MIN	MAX	MIN	MAX

PLANT	
T	[Kg/year]
AS	[Kg/year]
AS / T	[-]
LOSS	[Kg/year]
LOSS / T	[-]

Figure 14. Capture from the worksheet *Analysis*. Overall Results Analysis table.

Approaches to reporting

The Bow-Tie, as presented, it is a comprehensive tool that complements a proper Risk Assessment in the context of the OCS. Nonetheless, it may result not be suitable for application in all cases, and some facilities could require simplifications in terms of the input data, placing the emphasis on certain barriers and not others. Moreover, it cannot be ignored the fact that many facilities already have some register on the spills which are collected at the different barriers, which usually are later sent for recycling.

Hence, a set of adaptations of the Bow-Tie model are following presented, which are directed towards the objective of reporting the pellet losses across the plant. Each of these reporting models has a particular approach that makes it more adequate for different scenarios. The common denominator is that all of them are simpler to use than the Risk Assessment Bow-Tie model, and they require simpler inputs.

Before starting, the user must select which of the reporting models to use, according to the available information.

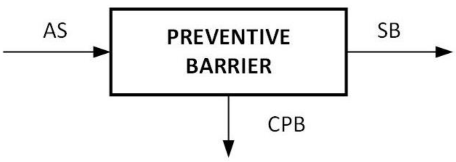
A. Bow-Tie Risk Assessment Model

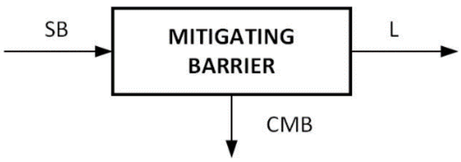
Applicable in case the following information is available:

- Measurements/Estimates of spills after the application of preventive barriers
- Estimate of annual spills without barriers
- Type of preventive barriers installed and their efficiencies

It must also be defined if the critical point approach or macro area approach is going to be followed.

The Loss (L) is calculated from spill quantities and loss probability. The equations that rule the body of preventive and mitigating barriers in a Macro Area are established as follows:





$$AS = CPB + SB$$

$$CPB = efficiency \times AS$$

$$SB = (1 - efficiency) \times AS$$

$$SB = CMB + L$$

$$CMB = efficiency \times SB$$

$$L = (1 - efficiency) \times SB$$

AS: annual spill
CPB: collected at the preventive barrier
SB: spill after preventive barrier

SB: spill after preventive barriers
CMB: collected at the mitigating barrier
L: loss

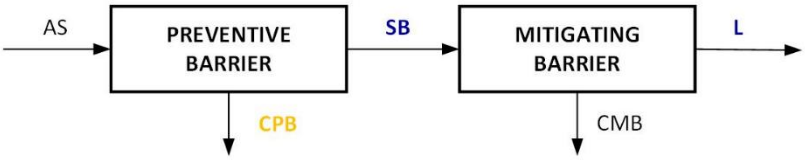
Barriers can be placed in series or parallel arranges. In each Macro Area, there are a total of n trails of barriers in parallel, and up to m barriers in series. The position of a barrier in this arrangement is indexed by i for the vertical position, and j for the horizontal position.

B. *Input data: volumes collected at preventive barriers*

Applicable in case the following information is available:

- Quantity of collected material at preventive barrier level ($\boldsymbol{CPB}$).
- Average efficiency of typical preventive barriers, including collection/retention trays or buckets and procedure for correct bag/octabin handling – range 60-80% for both types of barriers.
- The mitigating barriers are in place and their efficiency is evaluated in the same way as in the Bow-Tie Risk Assessment model.

This approach foresees a downgrade of the preventive barriers' efficiency – worst-case scenario –, given the lower level of available information.



$$SB = \left[\left[\prod_{j}^{m}\left(1 - \overline{efficiency}\big|_{barrier\ j}\right)\right]^{-1} - 1\right] \times CPB$$

$$LOSS = \sum_{j=1}^{m}\left[\left(f_j \times SB\right) \times \prod_{i=1}^{n}\left(1 - \overline{efficiency}\big|_{barrier\ j}\right)\right]$$

where f_i how the spilled quantity is divided into the different sets of mitigating barriers placed in both main macro area and peripheric/less accessible areas.

The layout of the model in Microsoft Excel is the same as in the Bow-Tie Risk Assessment Model, but this time the preventive barriers at a Macro Area level are reduced to only two inputs: the Preventive Barriers Efficiency (PBE), given as a range of Efficiency for the whole body of barriers in this Macro Area; and the Collected Material at Preventive Barriers (CPB), also given as a range of values. Once these inputs are established, there is a small calculation taking place backwards, which estimates the number of spills before the presence of the preventive barriers, but the main calculation occurs forwards, where the Spills after Preventive Barriers (SB) are calculated, and from there the whole evaluation of the body of mitigating barriers for the Macro Area takes place, as in the Bow-Tie Risk Assessment Model.

	-	
Throughput Annual (AT)	**Annual Spill (AS)**	**Throughput MA Handled**
[Kg/year]	[Kg/year]	[Kg/year]
-		-

Figure 15. Capture from the worksheet *Inputs*. Annual Spills backwards calculation.

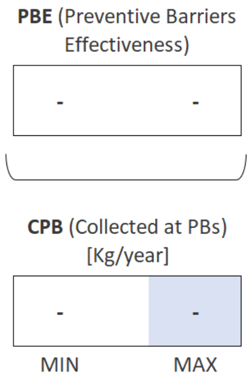


Figure 16. Capture from the worksheet *MA#*. Preventive Barriers inputs.

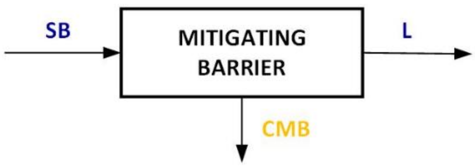
C. *Input data: volumes collected at mitigating barriers*

Applicable in case the following information is available:

- Quantity of collected material at mitigating barrier level ($\boldsymbol{CMB}$). This quantity both contains those material collected in various filters and the material recuperated by cleaning procedures.
- The contribution of the preventive barriers is not taken into account
- The mitigating barriers are in place and their efficiency is evaluated in the same way as in the Bow-Tie Risk Assessment model.

This approach foresees a back-calculation of the spill after barrier from the value of the collected pellets at the mitigating barriers (CMB).

Let's consider the amount of material collected in each trail of barriers in series, where the parallel groups of barriers are indexed with i.



$$SB = \sum_{i=1}^{n} \left[CMB_i \left(1 - \prod_{j=1}^{n} (1 - efficiency|_{barrier\ j}) \right)^{-1} \right]$$

$$SB = \sum_{i=1}^{n} \left[f_j \times \left(1 - \prod_{j=1}^{n} (1 - efficiency|_{barrier\ j}) \right)^{-1} \right] \times CMB$$

$$LOSS = SB - \sum_{i=1}^{n} CMB_i$$

where f_j is the factor that determines the fraction of material that flows in each of the barriers trails, j. Thus, $CMB_i = f_j \times CMB$. The sum of all the f_j factors must be the unit.

	-	
Throughput Annual (AT)	Annual Spill (AS)	Throughput MA Handled
[Kg/year]	[Kg/year]	[Kg/year]
-		-

Figure 17. Capture from the worksheet *Inputs*. Annual Spills backwards calculation.

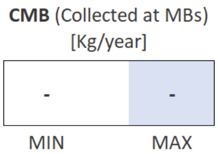


Figure 18. Capture from the worksheet *MA#*. Preventive Barriers inputs.

D. Input: pellets/powder waste sent to waste treatment

Applicable in case the following information is available:

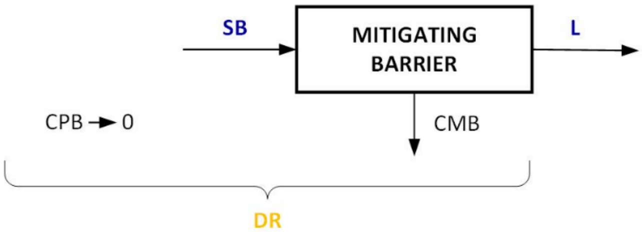
- Quantity of collected material sent to recycling and/or waste management ($\boldsymbol{DR}$)
- The contribution of the preventive barriers is not taken into account
- The mitigating barriers are in place and their efficiency is evaluated in the same way as in the Bow-Tie Risk Assessment model.

This approach foresees a back-calculation of the spill after barrier from the value of the collected pellets at the mitigating barriers (CMB), which is assumed to be the same than the recycling and/or waste management (DR).

The input values are the DR (Disposed/Recycled pellets) and the SFT (Split Factor for Throughput). The contribution of the preventive barriers is not taken into account.

$$DR = CPB + CMB$$

It is assumed that $CPB \to 0$, thus $DR \to CMB$.



$$SFT_i = T|_i \times \sum_{i=1}^{m} \left(\frac{1}{T|_i}\right)$$

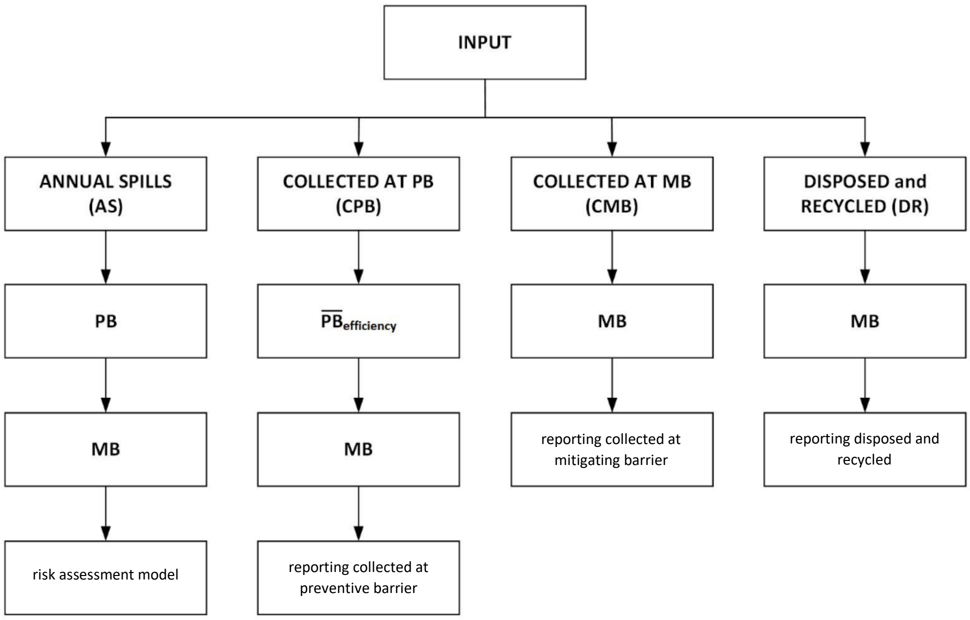
$$SB = \sum_{i=1}^{m} \left[(SFT_i \times DR) \times \left(1 - \prod_{j=1}^{n} (1 - efficiency|_{barrier\ j})\right)^{-1} \right]$$

$$LOSS = SB - DR$$

Decision-making Three

To sum up, depending on the information available, the user must decide which version of the model to use. The most important part of the inputs is the information about the quantity of spills or material collected at the barriers, depending on the case. This information is going to be crucial at the time of choosing a model. The four possibilities for spills quantities information are: the Annual Spills, the Collected material at Preventive Barriers (CPB), the Collected material at Mitigating Barriers (CMB), and the Disposed and Recycled material (DR).

In all the cases, the mitigation barriers are required to be fully defined and in place, no matter the model version, these barriers are a key component of the model and must be defined for each of the macro areas. Although, according to the set of information available, the version of the model to use is already selected and some other conditions must be fulfilled. For the case that the inputs are the Annual Spills, the preventive barriers must be totally defined, and the Risk Assessment Model is the choice to follow. For the Collected material at PB, it is also required to provide an average efficiency of this set of barriers in each macro area, and the Reporting Model Case I is the corresponding choice. For the case of Collected material at Mitigating Barriers (CMB), the choice is the Reporting Model Case II. And last, if the input data is the Disposed and Recycled material (DR), the version to use is the Reporting Model Case III.



A) Bowtie risk assessment model

The model itself is used for risk minimization with a focus on preventive barriers. It is therefore used after most obvious prevention and mitigation measures have been put in place and especially when there is scope for preventive measures to be implemented. It considers an exhaustive analysis of critical spill points.

B) Input: Quantity collected through preventive barriers

This approach considers spills collected in preventive barrier in a more holistic way. This means that it is mainly applicable when preventive barriers have already been implemented in all the plant macro-areas.

C) Input: Quantity collected through mitigating barriers

This approach is useful for a first evaluation of the potential for pellet loss. It has the disadvantage to get focus away from preventive barriers and should therefore be combined with other inputs as the company further minimises pellet losses.

D) Input: Quantity of plastics sent to waste treatment/disposal

This approach has the advantage to rely on the existing bookkeeping system of the company since tonnages sent to waste treatment/ disposal will be readily available from invoices. However, this approach should not be used in the following cases.

1) Pellet should be contained in a mostly closed system. Indeed, if waste is collected in preventive barriers. This indicator would lead to the paradoxical effect that the more efficient preventive barriers are, the higher the waste collected and therefore the estimated loss.

2) The facility should not generate significant amount of macroplastics waste (e.g., off-specs articles, trimming edges, offcuts or sprues from molding) which would be sent to recycling. Indeed, in this case the macroplastics waste will vastly exceed the weight of microplastics generated.
   This approach is therefore mostly applicable to resin production plants and specific masterbatching/compounding plants or converting plant with high internal recycling efficiency.

Why is no other indicator being used in the model?

Another indicator could be based on measurement of Total Suspended Solid in the water effluent. This indicator is useful to give context, but has several limitations:

1) Specific methods would have to be developed in order to distinguish the share of microplastics in the total suspended solid versus other contaminations such as sludge
2) Not all pellet loss would go through the sewer/ water effluent
3) There may be an important variability between two total suspended solids measurement. At the minimum to be relevant, first a cleaning of the sewer system before the sampling point should be considered

This indicator should therefore only be considered as a contextual element and should not be the basis for reporting.

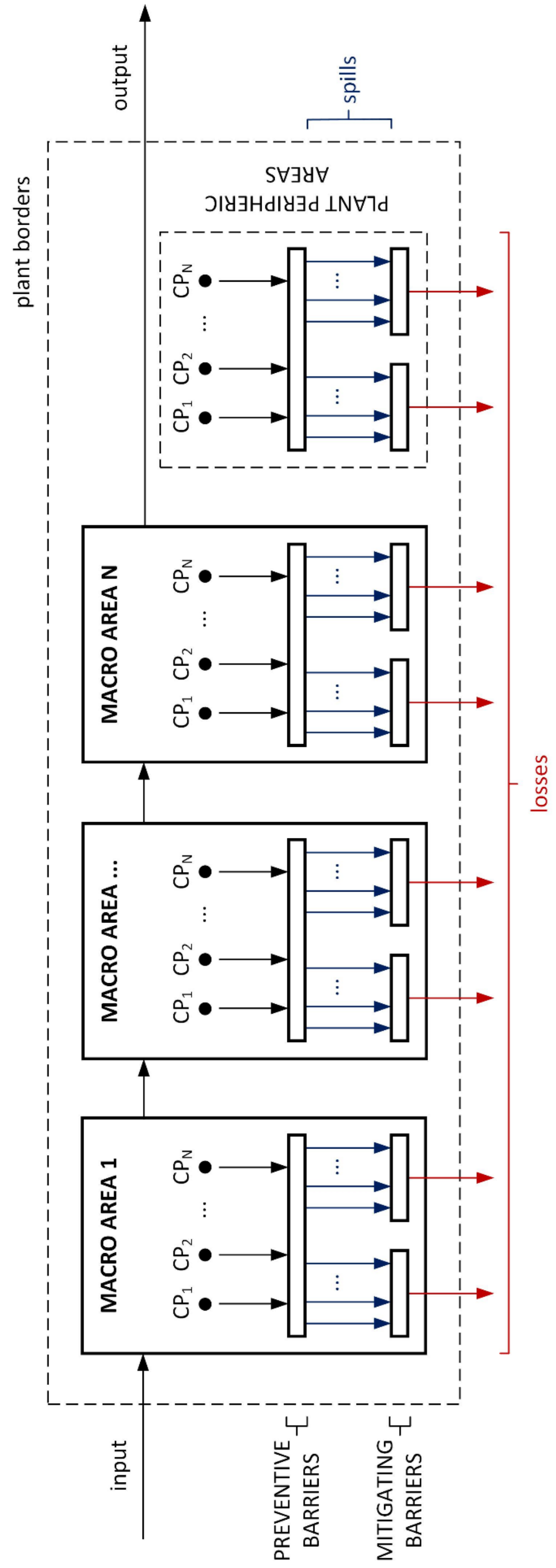


Figure A.1. Diagram of the plant MAs, and preventive/mitigation barriers distribution.