Bow-Tie Model Example

First, the structure of the model needs to be adapted to every particular case. 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.

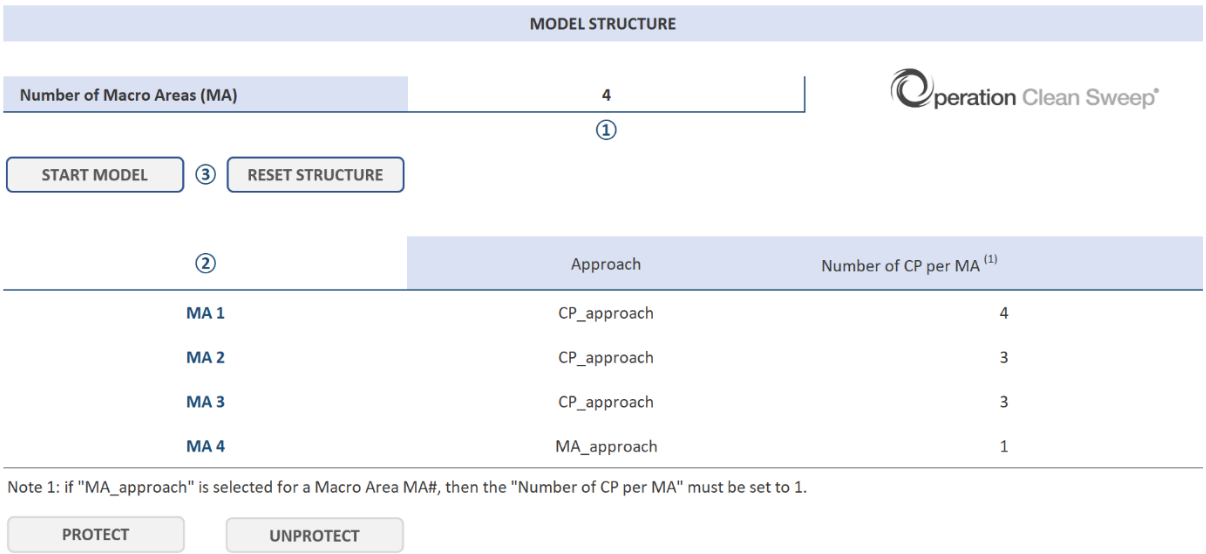

Figure 1. Capture from worksheet *Structure*.

For the purpose of creating an example, the case of a compounder is taken into consideration. The plant is divided into four main Macro Areas (MAs): *Goods In*, *Storage*, *Process*, and *Goods Out*. The Total Throughput of the plant is 10,400,000 Kg/year, and in each of the macro areas the following critical points (CP) are defined:

Table 1. Macro Areas and Critical Points.

Goods In	Storage	Process	Goods Out
Receiving area for bulk containers	Handling of sacks	Feeding points	Handling of sacks
Loading point for silo trucks	Handling of bulk containers	Shredders	Trucks loading/unloading
Connect/Disconnect location/operation	Goods dispatch/loading ramp	Mixing units	
Receiving area for sacks			

The example works with the two approaches available: the CP-approach and the MA-approach. Here below is the table with the information corresponding to the MA_1, under the CP-approach and the MA-approach as well. In this case, the spills and the throughput measurements are based on a period of 7 days and then annualized as Annual Spill (AS) and Throughput Annual (AT). However, this measurement period can be any number of days, and it does not need to be the same for all measurements together, but it may differ for each of them.

MACRO AREA 1	⑤ - ⑥	⑦				*data input*	
GOODS_IN		GOODS_IN					
Critical Point (CP)		Time [days]	Spill without Barrier [kg/time]	Throughput Measurement [Kg/time]	Throughput Annual (AT) [Kg/year]	Annual Spill (AS) [Kg/year]	SP
critical point 1	Receiving area for bulk containers	7	10.0	100,000	5,200,000	520	**0.03**
critical point 2	Loading point for silo trucks	7	7.0	120,000	6,240,000	364	**0.02**
critical point 3	Connect/Disconnect location/operation	7	1.0	80,000	4,160,000	52	**0.00**
critical point 4	Receiving area for sacks	7	40.0	100,000	5,200,000	2,080	**0.12**
						3,016	0.17

Figure 1. Data Input in MA_1 (*Goods In*).

For the CP-approach, it is assumed that all the material received is divided into equal parts of 100,000 Kg/week between the *Receiving area for bulk containers* and the *Receiving area for sacks*. Afterward, these quantities can be sent through the *Loading point for silo trucks* or a *Connect/Disconnect location/operation*. Note that the amount of spills without barriers is higher for the MA-approach than for the CP-approach, this is due to the higher level of uncertainty that this approach usually involves. For the remaining MA, similar reasoning is followed, with amounts that are congruent with the total throughput of material processed by the plant.

Once all the inputs for each of the MAs are filled with the information, a series of automated calculus takes place, as is shown in Figure 5-6. The spill probabilities are taken from the values already charged. For the preventive and mitigation barriers, their disposition, kind, and performance coefficients must be set up; as well as the *Main MA Factor*, which determines which proportion of the spills happen in the main parts of the macro area, in contrast with the ones happening in the peripheric areas. From this data, the efficiency coefficients and the reduction factor labels are automatically calculated, together with the amounts of pellets spilled and lost.

For the case of the MA_1, it is foreseen the following preventive barriers: for the *receiving area for bulk containers*, *collection trays,* and *procedure for handling octabins*; for the *loading point for silo trucks*, *collection trays,* and *tools cleaning (shovel, vacuum cleaner)*; for the *connect/disconnect location/operation*, *seals (on transfer equipment)* and *tools cleaning (shovel, vacuum cleaner)*; and for the *receiving area for sacks*, *collection trays* and *procedure for handling sacks*. All the performance parameters are set for each of the preventive barriers in place, and an effectiveness label is assigned to each of them. Then, the spill probability after barriers (SPB) and the spill after barriers (SB) are calculated, and a performance label is automatically calculated. For this example, in the MA_1, they are 0.027; 82.1 Kg/year; and A+, respectively. A parameter under the name of *Main MA Factor* is defined by the user, and determines the fraction of spills occurring in the main MA (SQ_1) and the fraction of spills in the peripheric areas (SQ_2) – both quantities are based on the maximum spill quantity after barriers.

Afterward, the mitigation barriers are set in place: for the main MA, *drain covers*, *water separation filters*, and *tools cleaning (shovel, vacuum cleaner)*; while for the peripheric areas, *tools cleaning (shovel, vacuum cleaner)*. Then, the total loss of the MA, LOSS, and the loss probability, LP, is calculated; alongside a general performance label, the *MA reduction factor*. For this example, in the MA_1, they are 1.54 Kg/year; 0.001; and A++, respectively.

A summary of the performance in each MA, along with the global performance in the whole plant, are presented. Here is the summary for the MA_1, where the spill probability after barriers (SPB), the loss probability (LP), the spill after barriers (SP), and the pellets Loss are included, for the CP and the MA-approaches, respectively.

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]	
0.026		0.0057		42.3	77.1	13.03	17.27				
				MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX

Figure 2. Summary MA_1.

Furthermore, a summary of the most important variables for the performance of this practice is offered, including the amount of the spill without barriers per unit of throughput, AS / T; and the losses amount per unit of throughput, LP (AS / 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	CP_approach	3,016	0.026	**0.063**	0.0057	77.1	**0.0190**
MA 2	CP_approach	6,240	0.071		0.0162	443.1	
MA 3	CP_approach	5,200	0.096		0.0259	498.5	
MA 4	MA_approach	3,120	0.028		0.0064	88.6	
Plant		**17,576**				**1,107.2**	

Note 1: Spill Probability after Barrier, SPB; Spill after Barrier, SB; Loss Probability, LP.
Note 2: The asterisk as a supraindex means that the factor corresponds to the Macro Area approach.

MA RESULTS ANALYSIS

SB / SB* [Kg/year]		LOSS / LOSS* [Kg/year]	
42.3	77.1	13.0	17.3
276.9	443.1	75.5	101.0
369.3	498.5	103.4	134.6
49.8	88.6	15.0	19.8
738.4	1,107.2	206.98	272.73
MIN	MAX	MIN	MAX

PLANT

T	[Kg/year]	10,400,000
AS	[Kg/year]	17,576
AS / T	[-]	0.17%
LOSS	[Kg/year]	272.73
LOSS / T	[-]	0.00262%

Figure 3. Overall results for the plant.

For this example, a total loss of 0.00262% is estimated, which is in accordance with the order of magnitude reported by some converting plants.

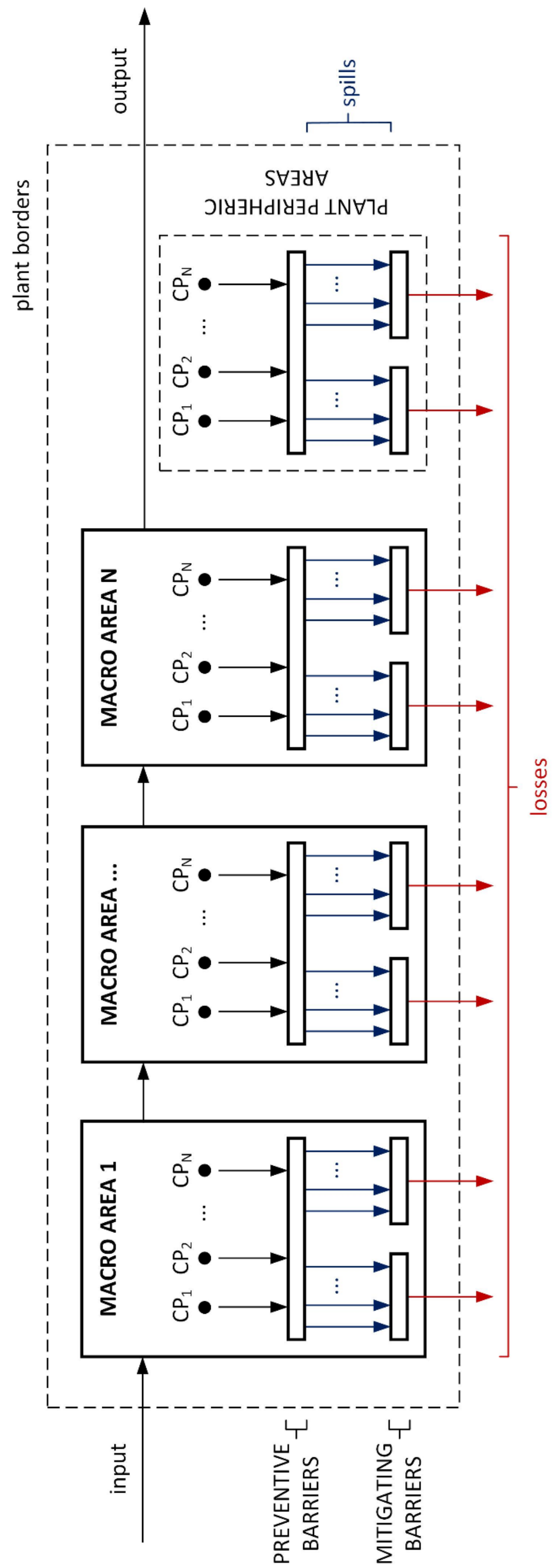

Figure 4. Diagram of the plant MAs, and preventive/mitigation barriers distribution.

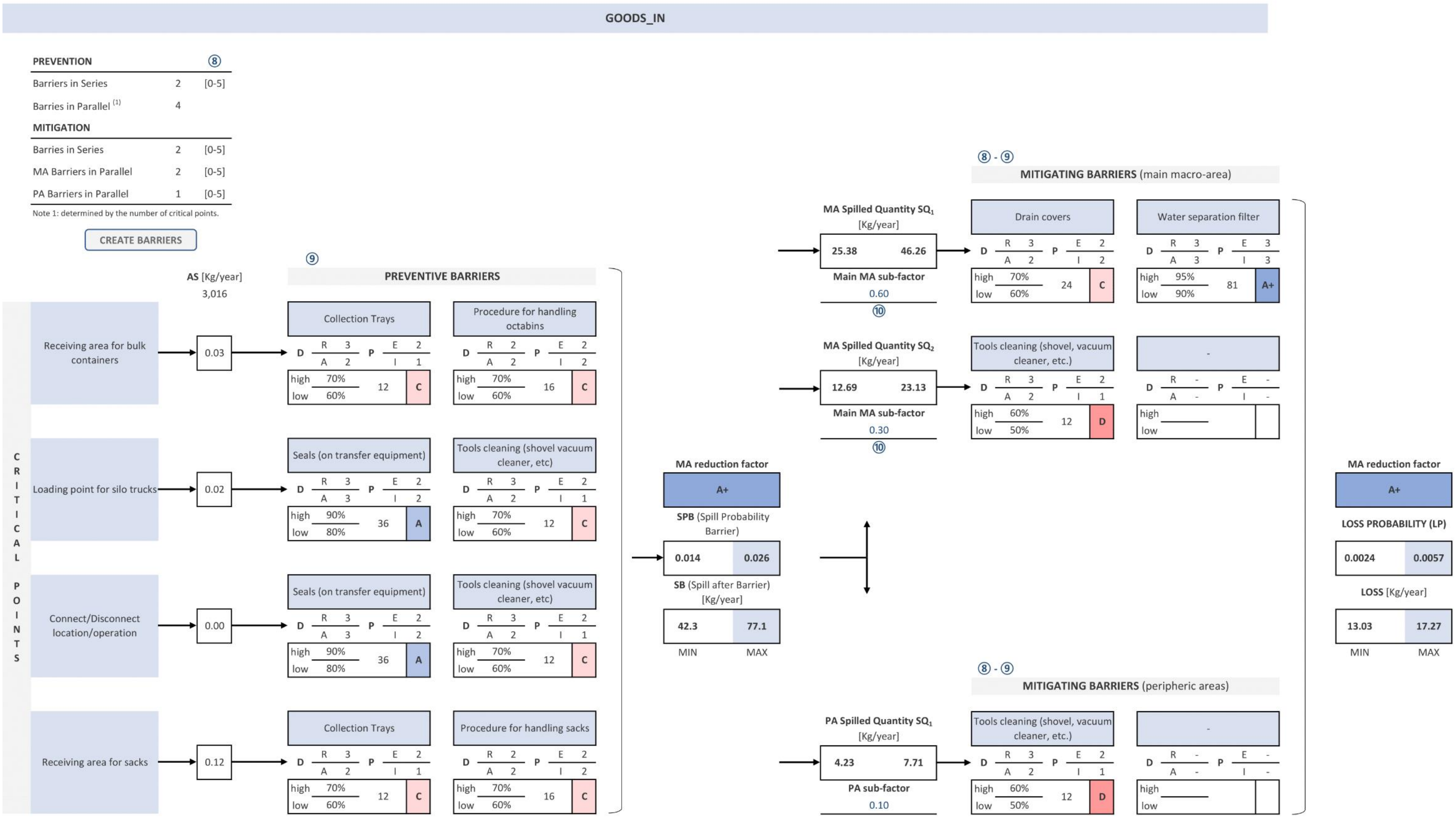

Figure 5. CP_1 spreadsheet.