Safety, Reliability and Risk Analysis: Beyond the Horizon – Steenbergen et al. (Eds)
© 2014 Taylor & Francis Group, London, ISBN 978-1-138-00123-7

Assessment of the losses due to business interruption caused by large-scale floods

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ABSTRACT: The economic consequences of floods, both in the form of material damage and losses due to business interruption, can be large. This paper presents a comparison between two approaches to determine the losses due to business interruption caused by large-scale floods. A model (HIS-SSM) containing a damage function approach and an Adaptive Input-Output model (ARIO) are applied to a hypothetical flood in The Netherlands. The results of the case study are compared to the costs of recent large-scale floods in the US and in Asia. The comparison shows that the losses due to business interruption are underestimated by HIS-SSM. The results of the ARIO model are in line with the figures from recent large-scale floods, but they depend strongly on how material damage is transformed to a production capacity. Furthermore, both models underestimate the losses due to business interruption if a unique object is flooded. We recommend to perform more validation studies with HIS-SSM and possibly replace the damage function approach with an input-output model approach for computing losses due to business interruption. Moreover, we recommend to perform more research on the relation between material damage and production capacity and to determine the consequences of flooding of unique objects on the level of the individual firm.

1 INTRODUCTION

In The Netherlands one of the most important methods to determine the level of flood protection is a cost-benefit analysis. In this analysis the costs (investment and maintenance costs of dikes) are compared with the benefits (a reduction of flood risks). Flood risks are defined as the product of probabilities and consequences of floods. The consequences are assessed using a software package known as *Hoogwater Informatie Systeem—Schade en Slachtoffer Module (HIS-SSM)* (KoK et al. 2005), High Water Information System—Damage and Victim Module. Recent large-scale floods show that the economic losses due to business interruption contribute a considerable amount to the total costs of the flood and should be taken into account in a cost-benefit analysis.

A recent report (RebelGroup Advisory 2009) states that the losses due to business interruption as a result of large-scale floods are probably underestimated with HIS-SSM. HIS-SSM uses a damage function approach to determine the losses due to business interruption, while relevant literature (Lequeux and Ciavola 2012) suggest that input-output models are (more) appropriate to determine such costs. An example of an input-output model is the Adaptive Regional Input-Output (ARIO) model (Hallegatte 2008).

The above research motivates to study the losses due to business interruption as a result of large-scale floods in more detail. The objective of this paper is to compare the performance of HIS-SSM and the ARIO model. The following research questions will be addressed:

- Is a damage function approach accurate in determining the losses due to business interruption?
- Are the losses due to business interruption underestimated by HIS-SSM?
- Is the ARIO model more accurate than HIS-SSM?
- In what conditions is the use of these models appropriate?

To answer these questions HIS-SSM and the ARIO model will both be applied to a hypothetical case in The Netherlands. The results of both methods are compared to figures of recent large-scale floods. Theoretical arguments are also given. Consequently, thisstudy yields more insight into the applicability of damage function and input-output models, especially for the assessment of losses due to business interruption.

The outline of this paper is as follows. Section 2 contains a definition of business interruption and an analysis of the business interruption as a result of recent large-scale floods. The two models are described in section refsec:models. A description of the case study and the results of both models can be found in section 4. Important challenges regarding these models are described in section 5. Conclusions and recommendations can be found in section 6.

2 BUSINESS INTERRUPTION

2.1 *Definition*

The losses due to business interruption are forgone value added that is not created due to the flood. If a firm is flooded there will be material damage, but the firm will also stop producing temporarily. During the production stop the firm does not create value added (being the difference between the turnover and the costs of the intermediate goods used in the production process). If the flood had not taken place the production would not have been stopped. The difference in added value with and without the flood are the losses due to business interruption caused by the flood.

The previous definition is based on an expansion of the classification used in (Merz et al. 2010). The expansion holds the use of the term damage for consequences which are not time dependent in the flood aftermath (like material damage) and the term losses for consequences which are time dependent (like the losses due to business interruption).

The preceding losses due to business interruption are direct losses due to business interruption. That is, the production stopped due to physical damage by the floodwater. A consequence of this production stop may be that other firms in the production chain (both forward and backward) also stop their production due to a lack of inputs or a lack of buyers. These losses are called indirect losses due to business interruption.

2.2 *Recent large-scale floods*

The considered floods in this section are the tsunami in Japan in 2011, the river floods in Thailand in 2011, the floods in New York and New Jersey due to hurricane Sandy in 2012 and the flooding of New Orleans by hurricane Katrina in 2005.

The material damage and losses due to business interruption in Japan were assessed by the government one year after the tsunami (Government of Japan 2012). The government expected real GDP to decrease by 6.8% on a quarterly basis directly after the flood. If the economy is restored again three months after, the total losses due to business interruption would amount to 8 trillion JPY. The material damage is estimated at 16.9 trillion JPY (about 205 billion USD), so the losses due to business interruption are equal to nearly half the material damage.

In Thailand the losses due to business interruption were assessed by the World Bank (World Bank 2012). Questionnaires were sent out to determine these losses due to business interruption. Information on the material damage was also collected by the questionnaires. According to the World Bank study, the losses due to business interruption were almost 800 billion THB (about 25 billion USD) and the material damage 630 billion THB. The losses due to business interruption were actually larger than the material damage in this flood, probably due to the long flood duration.

Mainly the states of New York and New Jersey were hit by hurricane Sandy. The losses due to business interruption are estimated to be between 20.6 and 25.3 billion USD (Muhr et al. 2012). The New York Governments Office estimated the material damage in thestate of New York to be 32.8 billion USD.[1] Chris Christie, the governor of New Jersey, estimated the total amount of material damage (including future prevention and mitigation measures) to be 36.8 billion USD.

Hurricane Katrina mainly caused damage in the state of Louisiana in 2005. The losses due to business interruption have been approximated with data from the Bureau of Labor Statistics. The total amount of jobs in the private sector in Louisiana dropped from 1.57 million to 1.42 million in September 2005 (one month after the disaster). It took until October 2007 to restore back to 1.57 million, after which it is assumed that business interruption did not take place anymore. Multiplying the amount of lost jobs with 2800 USD per month that the job was lost gives an approximation of the total amount of lost wages due to the flood of 4.5 billion USD. This figure does not include lost interest, dividends and profits. The total losses due to business interruption are therefore probably twice as large. The material damage was 30.1 billion USD (Kok et al. 2006).

The figures of material damage and losses due to business interruption are collected in Table 1. The material damage as percentage of GDP has been added to give an idea of the scale of the flood. The table shows that the losses due tobusiness interruption are quite large compared to the

[1]Available at http://www.governor.ny.gov/assets/documents/sandyimpactsummary.pdf accessed 21/12/2012.

Table 1. Losses due to business interruption of recent large-scale floods. The losses due to business interruption (LBI) are expressed as a share of the material damage. The Material Damage (MD) is expressed in billion USD and as a share of the GDP in the year of the flood. For hurricane Sandy the GDP is based on the states of New York and New Jersey. For hurricane Katrina the GDP is based on the state of Louisiana.

Event	MD [b$]	MD [%]	LBI [%]
Japan 2011	205	3.6	47.3
Thailand 2011	21	6.0	125.0
Hurricane Sandy 2012	70	3.7	37.5
Hurricane Katrina 2005	30	15.4	30.0

material damage of the flood and should definitely be considered in a cost-benefit analysis regarding the level of flood protection.

3 MODELS

3.1 *HIS-SSM*

HIS-SSM considers direct material damage (to cars and buildings for example) and losses due to business interruption (both direct and indirect). The method combines GIS data with flood parameters to be able to calculate the expected costs. The flooded area is divided into cells (size 100 meters by 100 meters).

The direct material damage is calculated with equation 1, in which D is the total damage in the considered cell, α_i is the damage factor for category i, n_i the number of units in category i and S_i the maximum damage perunit in category i. Considered categories for material damage are houses, firms, cars, roads and agricultural area among others.

$$D = \sum_{i=1}^{n} \alpha_i n_i S_i \tag{1}$$

The damage factor α_i is based on the water depth. This factor is calculated using damage functions. An example of a damage function can be found in Figure 1 (Kok et al. 2005). According to this damage function, a flood depth of five meters or more indicates that the building is completely damaged. If the water depth is one meter, the damage to the building is equal to 50% of the maximum damage.

The number of units n_i is based on a GIS database, which consists of the amount of objects in each grid cell for all categories. The maximum damage per unit S_i is constant for all cells (but differs per category obviously).

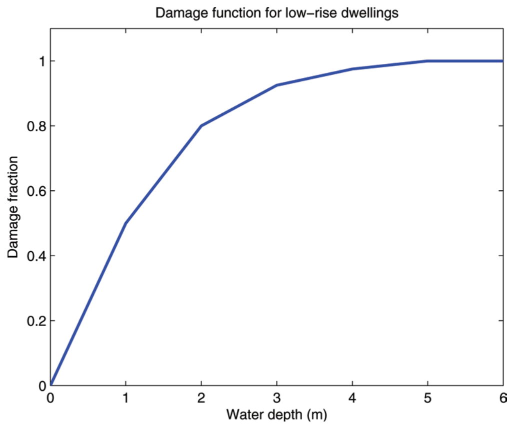

Figure 1. Example damage function.

The same procedure is used to determine the direct and indirect losses due to business interruption. To determine the losses due to business interruption α_i is still a damage factor, n_i is the amount of jobs in sector i and S_i is the maximum amount of losses due to business interruption per job for sector i. The damage function used to determine α_i is the same for each sector and the same for material damage to firms.

This methodology does not allow for large changes in the size of losses due to business interruption as a percentage of the material damage. The losses due to business interruption behave linearly with regards to the scale of the flood. The losses due to business interruption can only increase if more firms are flooded (or the water depth increases), but the material damage also increases in such a case.

3.2 *ARIO model*

The ARIO model only considers the losses due to business interruption. The material damage is an input to the model. A full description of the model can be found in (Hallegatte 2008). The core of the model has been displayed in Figure 2.

The material damage is an input to the model. This material damages has two consequences in the model. The production capacities are reduced because facilities necessary in the production process (like machines and buildings) are damaged. The total demandon the other hand increases, as the damage needs to be repaired. This increases demand to firms in the manufacturing (furniture, cars) and construction (building repairs) sectors.

The total demand and production capacity determine the actual production. The total demand basically contains what society wants the

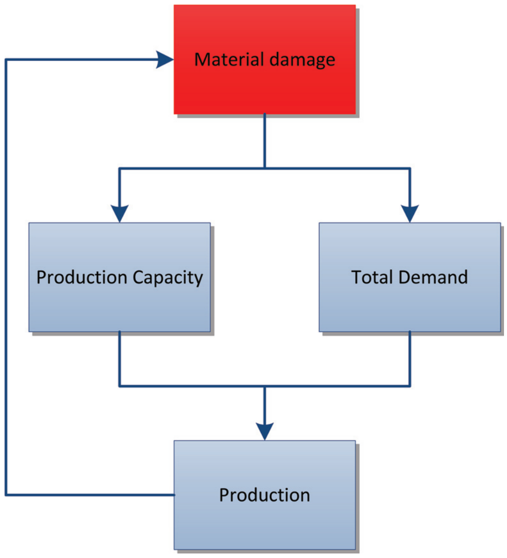

Figure 2. Simplified scheme of the ARIO model.

economy to produce and the production capacity determines how much of the desired production can be delivered. In the first several time steps the production capacities are usually smaller than the total demand. The production is determined for a certain time period (which is one month in this paper).

After the amount of production has been determined this production has to be divided. A part of the production will be used by local consumers, a part of the production will be exported and the final part will be used to repair the material damage. When acertain amount of production is used to repair the material damage the remaining material damage reduces by this amount. The remaining material damage thus reduces in time.

In the following time step, the amount of material damage has been reduced. The consequence is that the production capacity slightly increases (compared to the production capacity in the previous time step) and the total demand reduces. This goes on for anumber of time steps until all the material damage has been repaired and the economy has returned to the pre-disaster situation.

The total value added created after the flood can be simulated using this model. When the total value added is compared to the value added before the flood, the losses due to business interruption can be determined by integrating the differences between these two.

An important difference with HIS-SSM is that the relative amount of the losses due to business interruption increases as the scale of the flood increases. The more material damage, the smaller the production capacity and thus the longer the recovery period takes. A longer recovery period increases the losses due to business interruption.

4 CASE STUDY

4.1 *Description of the Lopik dike breach case*

The case covers the hypothetical flooding of a large part of the area known as the *Groene Hart* or Green Hart. A dike breach occurs near the small town of Lopik (situated between Rotterdam and Utrecht) in The Netherlands. The river Lek floods large parts of the province of South Holland. The considered discharge in the river Lek has a return period of 2000 years.

The cities of Gouda and Woerden are completely flooded. Small parts of Rotterdam and Utrecht are flooded as well. Most of the flooded area is either agricultural area or recreational area (nature). Railroads and highways are also flooded, of which the railroad between Utrecht and Gouda (which continues to Rotterdam and The Hague) is the most important. This is supposed to be one of the worst possible floods in The Netherlands regarding material damage and losses due to business interruption.

4.2 *Input data*

The input data required to determine the material damage and the losses due to business interruption with HIS-SSM is the water depth in each considered cell. The Dutch project *Veiligheid Nederland in Kaart* or Mapping Safety in The Netherlands supplied the water depths for this case. The water depths are determined with a hydrodynamic model. The other databases with the spatial distribution of houses, firms, roads and many other objects is incorporated in the software of HIS-SSM.

The ARIO model requires a detailed description of the considered economy in the form of input-output tables. These tables are available in the national accounts published annually in The Netherlands (Centraal Bureau voor de Statistiek 2012). The considered table consists of 21 sectors to describe the economy. The material damage has been based on the results of the material damage module of HIS-SSM. Parameters describing processes like overproduction, substitution and prices are assumed equal to the parameters in (Hallegatte 2008) due to a lack of data.

4.3 *Comparison of model results*

Both models have been applied to the Lopik dike breach case. The results can be found in Table 2.

Table 2. Comparison of recent events with model outcomes. The losses due to business interruption (LBI) are expressed as a share of the material damage. The Material Damage (MD) is expressed as a share of the GDP in the year of the flood. For hurricane Sandy the GDP is based on the states of New York and New Jersey. For hurricane Katrina the GDP is based on the state of Louisiana.

Event	MD [%]	LBI [%]
Actual floods		
Japan 2011	3.6	47.3
Thailand 2011	6.0	125.0
Hurricane Sandy	3.7	37.5
Hurricane Katrina	15.4	30.0
Model	MD [%]	LBI [%]
Lopik dike breach		
HIS-SSM	3.1	**3.8**
ARIO	3.1	**29.0**

The material damage just after the flood is not determined by the ARIO model, but it is an input to the model. This is the reason why the material damage is the same for both models.

The material damage as percentage of GDP has been added to give an idea of the scale of the flood. As can be seen, the losses due to business interruption determined by HIS-SSM are very small compared to the figures found in actual large-scale floods. The results of the ARIO model are more in line with the recent floods, but these results depend strongly on the Damage-To-Production-Capacity-Ratio (DPCR) parameter. This parameter has been determined differently than in (Hallegatte 2008). This is explained in section 5.1.1.

The relative contribution of the losses due to business interruption in the total costs of the flood is not expected to increase significantly as the scale of the flood increases in HIS-SSM. This is due to the linear behavior of the losses due to business interruption in the considered model. If a similar but twice as large area is flooded (with the same water depths) both the material damage and the losses due to business interruption would double, their relative contribution to the total costs of the flood does not change.

In the ARIO model the losses due to business interruption increase non-linearly with the initial material damage. This is illustrated in Figure 3. This figure has been made by scaling the material damage of the flood (so the relative breakdown of the material damage does not change).

This figure also includes the results of HIS-SSM in case the size of the flood would be scaled. The figure shows that especially for very large floods the differences between the two models are large. The

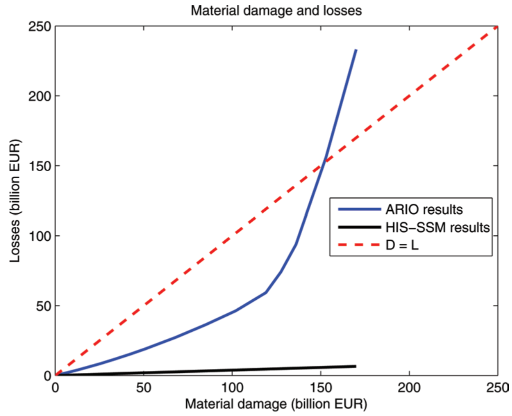

Figure 3. Losses due to business interruption for increasing material damage based on the Lopik dike breach case. The blue line indicates the results of the ARIO model after scaling the material damage. The black line indicates the results of HIS-SSM as a result of the scaling of the flood. The dotted red line indicates where the losses due to business interruption are equal to the material damage.

relation between material damage and losses due tobusiness interruption as a result of the ARIO model seems more in line with reality, because the more material damage the fewer production capacity is available to repair the damage. This increases both the duration of the business interruption and the amount of firms interrupted, leading to a non-linear relation between the two. HIS-SSM only considers the increase of the amount of firms, not the increase of the duration (which is only dependent on the water depth in the model).

4.4 *Preliminary conclusions*

HIS-SSM probably underestimates the losses due to business interruption caused by large-scale floods and the relative contribution does not differ much for floods of a different size. The results of the ARIO model are more in line with figures of actual floods, but the DPCR parameter in the model has a very strong influence on the results. A sensitivity analysis of the ARIO model and a more detailed treatment of the DPCR can be found in section 5.1.

5 CHALLENGES

5.1 *Model robustness*

To test the robustness of the ARIO model a different way to transform material damage to production capacity is used in this paper compared to (Hallegatte 2008). A sensitivity analysis is performed as well.

5.1.1 *Damage to production capacity*

The Damage-to-Production-Capacity-Ratio (DPCR) has a strong influence on the losses due to business interruption in the ARIO model. This parameter is used to calculate the remaining production capacity as a result of the material damage in a certain sector with equation 2.

$$Y_{max} = Y_B \left(1 - \frac{D}{K\,V} \right) \alpha \tag{2}$$

Y_{max} is the maximum production capacity of the considered sector, Y_B is the production before the flood, D is the amount of material damage, K is the DPCR, V is the value added before the disaster and α is the amount of overproduction.

In the original model the DPCR was set to 4 for all sectors (Hallegatte 2008). This can be interpreted as every 4 units of material damage reduces the production capacity by such an amount that the annual value added is reduced by 1 unit. The DPCR was based on the total capital in a sector divided by the annual value added. This does however not take into account that many production processes are series systems and that they completely stop if one of the components is disturbed. This procedure overestimates the available production capacity.

A different approach has been used to determine the DPCR in this paper. The DPCR is the link between production capacity and material damage. Using HIS-SSM the available production capacity immediately after the flood can be approximated. Combining this information with the material damage leads to the DPCR. Consequently, the DPCR can be used to determine the production capacity in all the time steps after in the ARIO model.

An important assumption in this methodology is that the production capacity relates linearly to the amount of jobs. The amount of 'flooded' jobs per sector can be determined with HIS-SSM and the total amount of jobs per sector is also available. If the amount of lost jobs is x% of the total amount of jobs, then the remaining production capacity of the considered sector is also reduced by x% (compared to the pre-flood production capacity).

The method can be expanded to include the water depth as a variable to determine the production capacity. As argued before, the water depth is not a good indicator of the duration of the business interruption. It is a good indicator for the amount of production capacity left immediately after the flood however. For this reason, the amount of lost jobs is determined using a (simple, linear) damage function as can be found in Figure 4.

The result of this damage function would for example be that if the water depth in a firm with 10 employees were 1.5 meters, 5 jobs would be lost. The production capacity of this firm would be reduced by 50% immediately after the flood. The example damage function has its slope discontinuity at 3 meters. If the water depth is larger than this 3 meters, the production capacity of the firm is reduced to 0 immediately after the flood. The previous results of the ARIO model were based on a damage function with a slope discontinuity at 2.5 meters. In Table 3 the results of other linear damage functions can be found.

The results show that the outcome of the ARIO model depends very strongly on the DPCR. This makes the relation between material damage and production capacity important when considering the losses due to business interruption.

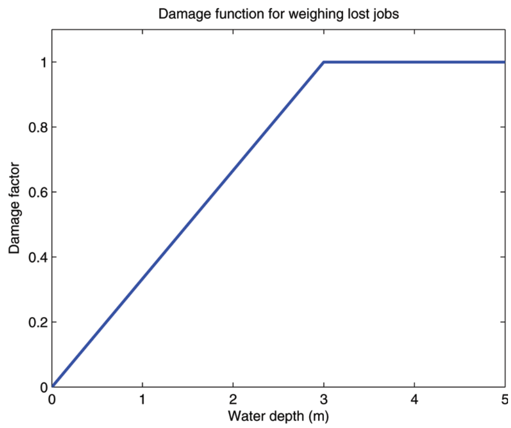

Figure 4. Example damage function to determine the amount of lost jobs.

Table 3. Losses due to business interruption for different DPCRs based on damage functions to determine the weighed amount of lost jobs. Slope discontinuity in meters, losses in million EUR.

Slope discontinuity	Average DPCR	Losses [m]
1.0	1.42	11,300
1.5	1.63	8,946
2.0	1.95	6,701
2.5	2.35	4,968
3.0	2.74	3,646
3.5	3.17	2,613
4.0	3.62	1,838
4.5	4.07	1,246
5.0	4.55	778

5.1.2 *Sensitivity analysis*

A sensitivity analysis has been performed to determine the influence of certain constants on the results of the ARIO model. This showed that the constants determining the overproduction parameter (α in equation 2) have a large influence on the results, as can be seen in Figure 5. The figure shows that the losses due to business interruption are smaller if the maximum overproduction increases or the time scale decreases. A reduction of the time scale means that firms aremore flexible, they can increase and decrease the amount of overproduction on short notice.

The influence of prices can be found in Figure 6. The figure shows that the influence of prices on the losses due to business interruption is quite small in the ARIO model. The constant γ_p describes prices as a result of the mismatch between total demand and actual production. This parameter thus describes producer behavior. The response of final demand to the new prices is modeled by the ξ constant, so this constant describes consumer behavior. The influence of the γ_p constant is noticeable, but very small compared to the influence of the overproduction constants.

Other parameters like those describing substitution and the macro-economic indicator have a small influence on the results as well, though a little more influence than the price parameters.

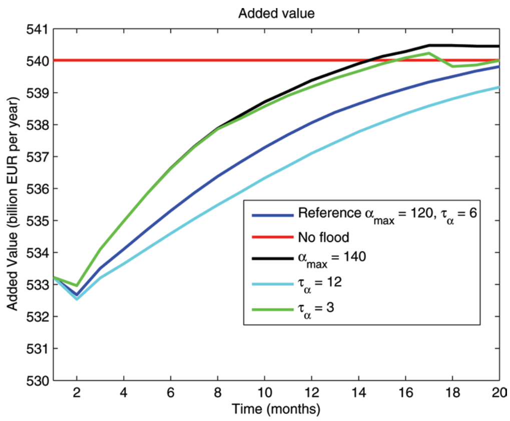

Figure 5. Value added as a result of different overproduction constants. α_{max} is the maximum overproduction and τ_α describes the time scale in which the overproduction can be changed.

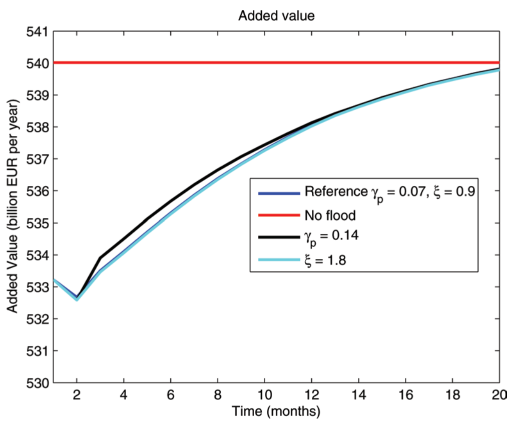

Figure 6. Value added as a result of different price constants. γ_p describes prices and ξ describes the response of final demand to new prices.

5.2 *Unique firms*

Both HIS-SSM and the ARIO model use a sector approach to determine the losses due to business interruption. In a sector approach all firms are divided into several sectors, for example farms belong to the agricultural sector and power plants belong to the utilities or energy sector. Next the assumption is made that the value added per job is the same in a sector (HIS-SSM) or that firms within the same sector can provide substitutes for each other (ARIO model).

This may lead to an underestimation of the consequences of floods. The aggregation level on which these models work is usually quite high. The number of sectors used to describe the economy usually ranges between 10 and 30. The interruption of unique, critical firms or infrastructure is not taken well into account because other firms in the same sector are assumed to be able to provide substitutes for the critical firm. This will be explained with an example.

The Rotterdam port area in The Netherlands contains a large variety of industries, including a large diesel refinery. The terrain height of this diesel refinery is slightly (approximately 1 meter) lower than the surrounding industrial area. Assuming that the water depth at the diesel refinery is 0.7 meters during a flood, the costs of flooding of this firm can be determined with HIS-SSM and the ARIO model. The results have been collected in Table 4.

Table 4. Costs of the diesel refinery flood according to HIS-SSM and the ARIO model. All costs in thousands EUR.

Category	HIS-SSM [k]	ARIO model [k]
Material damage	3,141.0	3,141.0
Direct losses	967.5	20,000.0
Total	4,108.5	23,141.0

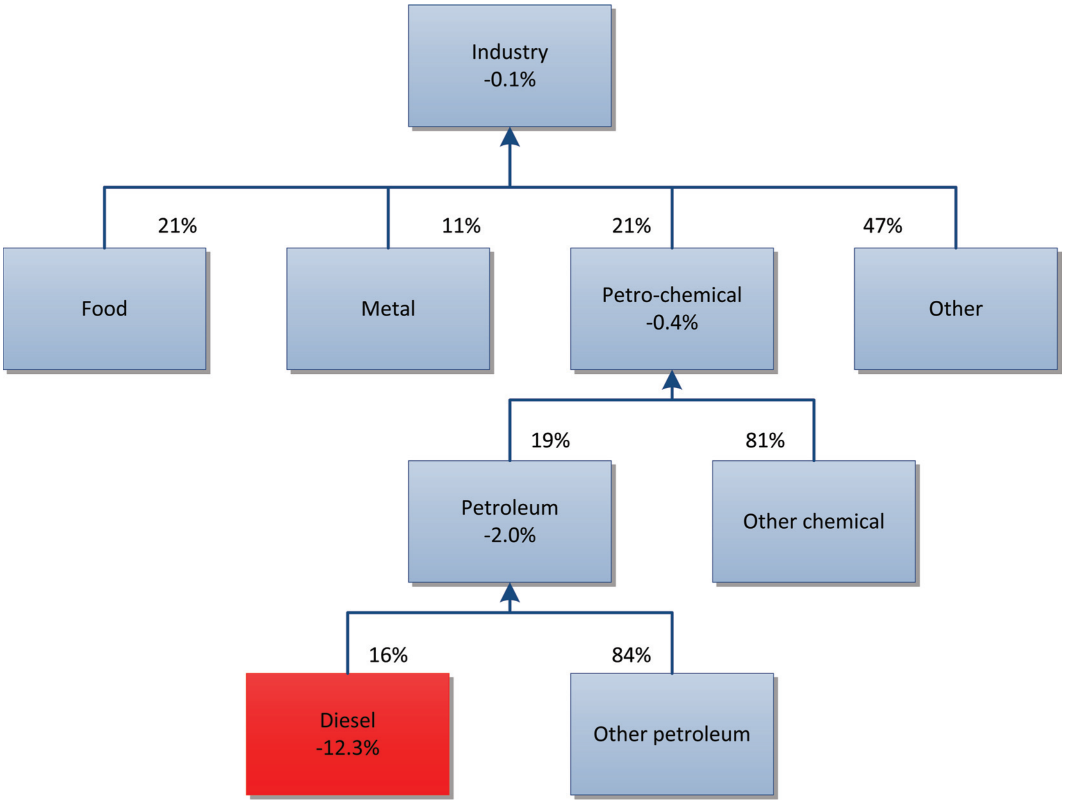

Figure 7. Industry sector tree. The figures in the boxes give the production capacity reduction of the box. The figures near the lines indicate the size of the box relative to the size of the box above.

The difference in costs is quite large. The total costs are in the order of EUR millions.

The considered diesel refinery has a production capacity of 800,000 tonnes of diesel annually. The total diesel consumption in The Netherlands was 6,519,000 million tonnes in 2011.[2] The flooded refinery actually produces about 12% of the Dutch diesel consumption. Both firms and consumers are very dependent on diesel, it is hard to find a substitute for the fuel on a short notice. A possible solution to this problem would be to import diesel to increase the availability.

Both HIS-SSM and the ARIO model do not fully consider the possible consequences of the flood. This can be explained with Figure 7. The numbers are based on (Centraal Bureau voor de Statistiek 2012). A reduction of the production capacity in the diesel refinery sector of 12% is a reduction of 2% of the total petroleum refining sector (this sector also includes gasoline and LPG). When the petro-chemical sector is considered, the reduction is only 0.4%. For the whole industry sector (including food, metal andothers) the production capacity reduction is only 0.1%. HIS-SSM and the ARIO model work on the industry sector scale. The underlying production capacity reduction of 12% in the diesel refinery sector is considered to be the same as a 0.1% reduction ofthe industry sector as a whole, leading to an underestimation of the possible consequences.

There are two criteria to determine whether a firm is critical or not. There are no substitute products/services available for the considered firm on a short notice and the effects of the interruption of the firm should be geographically larger than the flooded area. Examples of these firms are the gas fields in the north of The Netherlands, large power plants, telecommunication centers and logistic centers like the port of Rotterdam. An interruption of these firms or infrastructure may have very large consequences in The Netherlands. These

[2]http://statline.cbs.nl/StatWeb/publication/?DM=SLNL&PA=80101NED&D1=8&D2=a&D3=257&VW=T accessed 20-3-2013.

effects should be considered on the individual firm level to be able to understand what is going to happen in case of a flood.

6 CONCLUSION

6.1 *Conclusion*

A damage function approach can be used to determine the material damage, but the losses due to business interruption can only be assessed for small scale floods with this approach. When the production capacity of the construction sector starts to have an influence on the duration of the business interruption the model becomes less accurate.

HIS-SSM probably underestimates the losses due to business interruption as a result of large-scale floods. The relative contribution of the losses due to business interruption to the total costs of the flood does not increase when the size of the flood increases. The results of the ARIO model are more in line with figures of actual floods, but the outcome of this model depends strongly on the DPCR.

The relation between material damage and production capacity is important to determine the losses due to business interruption, but still much is unknown about this topic. The uncertainty in the results of the ARIO model are mainly due to this knowledge gap. The same knowledge gap can be found in HIS-SSM, as the damage function used to determine the material damage for firms is also used to determine the losses due to business interruption.

Both models underestimate the losses due to business interruption if a unique, critical firm or infrastructure is flooded. This is a result of the sector approach in both models in which all firms are divided into sectors. Firms within the same sector areassumed to be able to provide substitutes for each other, but with unique firms and infrastructure this is not possible.

6.2 *Recommendations*

The losses due to business interruption module of HIS-SSM should be validated more thoroughly with recent floods. The use of a cost-benefit analysis in decision making requires that both the costs and benefits are known to a certain degree. If HIS-SSM structurally underestimates the losses due to business interruption (which are a considerable cost) decision making might be undermined by the wrong estimates.

An essential step in the modeling of business interruption is the relation between material damage and the production capacity. Every model takes this step one way or the other. There should be more research on this topic to increase the accuracy of models used to determine the losses due to business interruption. Instead of just considering the absence of working capital goods, perhaps also the unavailability of labor (due to injuries, fatalities or evacuation) can be taken into account to determine the production capacity.

The interruption of unique, critical firms should be taken into account on the level of the individual firm. Currently these firms or infrastructures are divided into sectors which may lead to a severe underestimation of the consequences of floods.

ACKNOWLEDGEMENTS

The authors would like to thank project *Veiligheid Nederland in Kaart* for making the hydrodynamic computations for the case study available.

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