Level of Service (LOS) based Data Fusion

to enhance the Quality of Traffic Information

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Abstract

Today, the road side level of service (LOS) information is a commonly used measure for describing the current road network efficiency. It characterizes traffic flow or travel times by a small number of discrete traffic quality classes (e.g. free flow, dense traffic, traffic jam) and is one of the most popular kinds of traffic information in road transportation. In this context, LOS-based information is often obtained from single traffic data sources like floating car data or detector data without combining them systematically. In order to improve the quality of LOS-based traffic information a high level fusion approach is needed which integrates LOS data from various data sources. This contribution suggests a new methodology using a quality-weighted median approach to efficiently and generically fuse these LOS data. It principally handles the common discretization schemes and provides a stochastic algorithm for transforming LOS data of arbitrary scales. The new methodology is described together with a use case for a region in Germany and the technical description of the prototypical LOS data fusion software module as designed and implemented by the Institute of Transportation Systems of the German Aerospace Center (DLR).

Keywords: level of service, data fusion, traffic data, traffic information, floating car data, loop detector, system architecture

Introduction

In road transport, one great challenge for traffic information services is to provide reliable traffic information as to reach high acceptance from the travelers. Among the existing road traffic information like accidents or construction sites, the level of service (LOS) information plays an important role. In this context, LOS information is usually obtained from single data sources like floating car data, floating phone data, stationary detectors (inductive loops …) or video detection. In case of the availability of LOS data from more than one data source, a high level data fusion aims to generate some more reliable and accepted LOS traffic information. In the literature, there are different LOS standards using different scales, typically reaching from three up to six levels (e.g. see [1, 2]). Figure 1 illustrates an example of such an LOS-based data fusion using two LOS data sources, namely Floating Car Data (LOS_{FCD}) and loop detector data (LOS_{DET}). In this case, both input data sources formally use the same LOS standard (3 classes) and in addition provide a quality value (w_{FCD}, w_{DET}) for each data point. Fusing the inputs then provides a new LOS value (LOS_{FUSION}) with a fused quality value (W_{FUSION}) as well as the information about its scale.

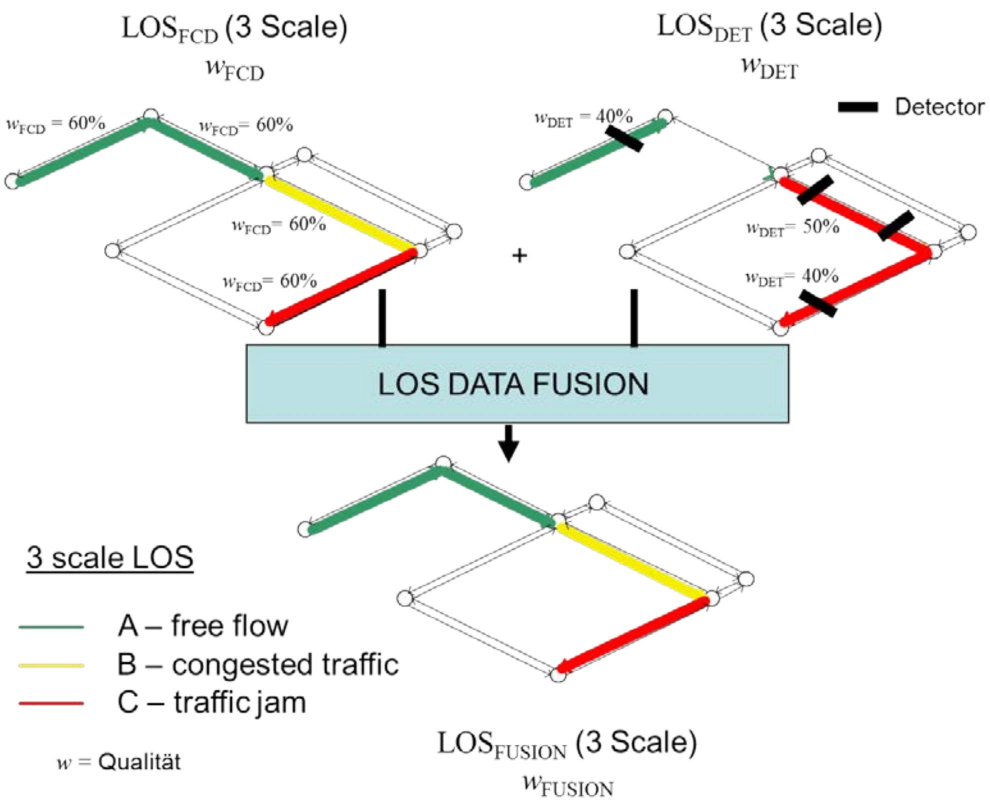


Figure 1: Example of LOS based data fusion

This paper describes the basic architecture and important parts of the new high level LOS data fusion (LOS-DF) system.

The structure is as follows: after Section 1, this introduction, Section 2 describes roughly the key aspects of the new LOS data fusion algorithm as well as a stochastic algorithm for transforming LOS data between different scales. An overview about the system architecture and a description of the components of the data fusion software module is given in Section 3. Test results for an exemplary region in Germany are presented in Section 4, leading to some conclusions in Section 5.

The LOS data fusion algorithmic concept

This paper is not going to present the details of the algorithmic concept of the LOS based data fusion but will principally focus on the technical aspects of the prototypical realization as designed and implemented by the German Aerospace Center (DLR). The proposed LOS based data fusion method that uses a quality-weighted median approach has been fully described in a complementary publication (see [3]) and consists of three separate components:

1. Transforming the scale: provides a stochastic algorithm for transforming LOS data between arbitrary scales. Since LOS input data can have different scales, all inputs need to be normalized to the same scale before starting the data fusion process.
2. Fusion of data: computes a fused LOS based on a weighted median approach
3. Assessing the quality of the fusion result: provides the algorithmic method to assess the quality of the fused data dependent on the input qualities.

Figure 2 shows the main workflow of the process of fusing the LOS data and the relationship between the components.

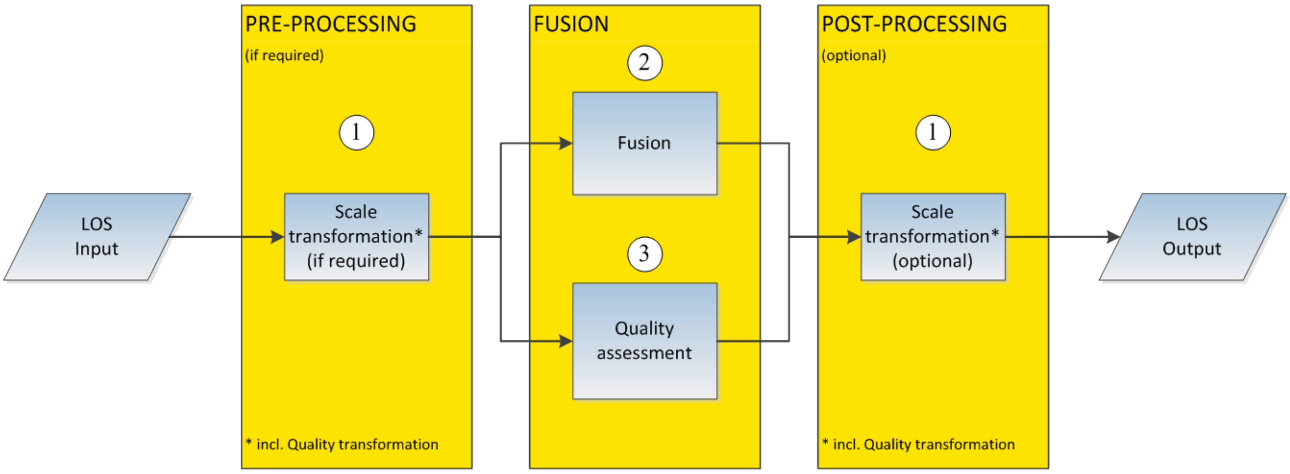


Figure 2: LOS based data fusion workflow

System architecture of the LOS data fusion

Figure 3 gives an overview about the realized LOS data fusion module (*DLR LOS-DF-Module*) in the context of the overall process chain (data sources → LOS data fusion → use/visualization of traffic states).

It consists of several components like map loader, data importer and synchronizer, data exporter, a shape file generator and an LOS calculation unit in case of raw data instead of LOS data import. Each component provides specific functionalities. The core component of the system is the data fusion unit. It implements the proposed LOS data fusion algorithm as presented in [3].

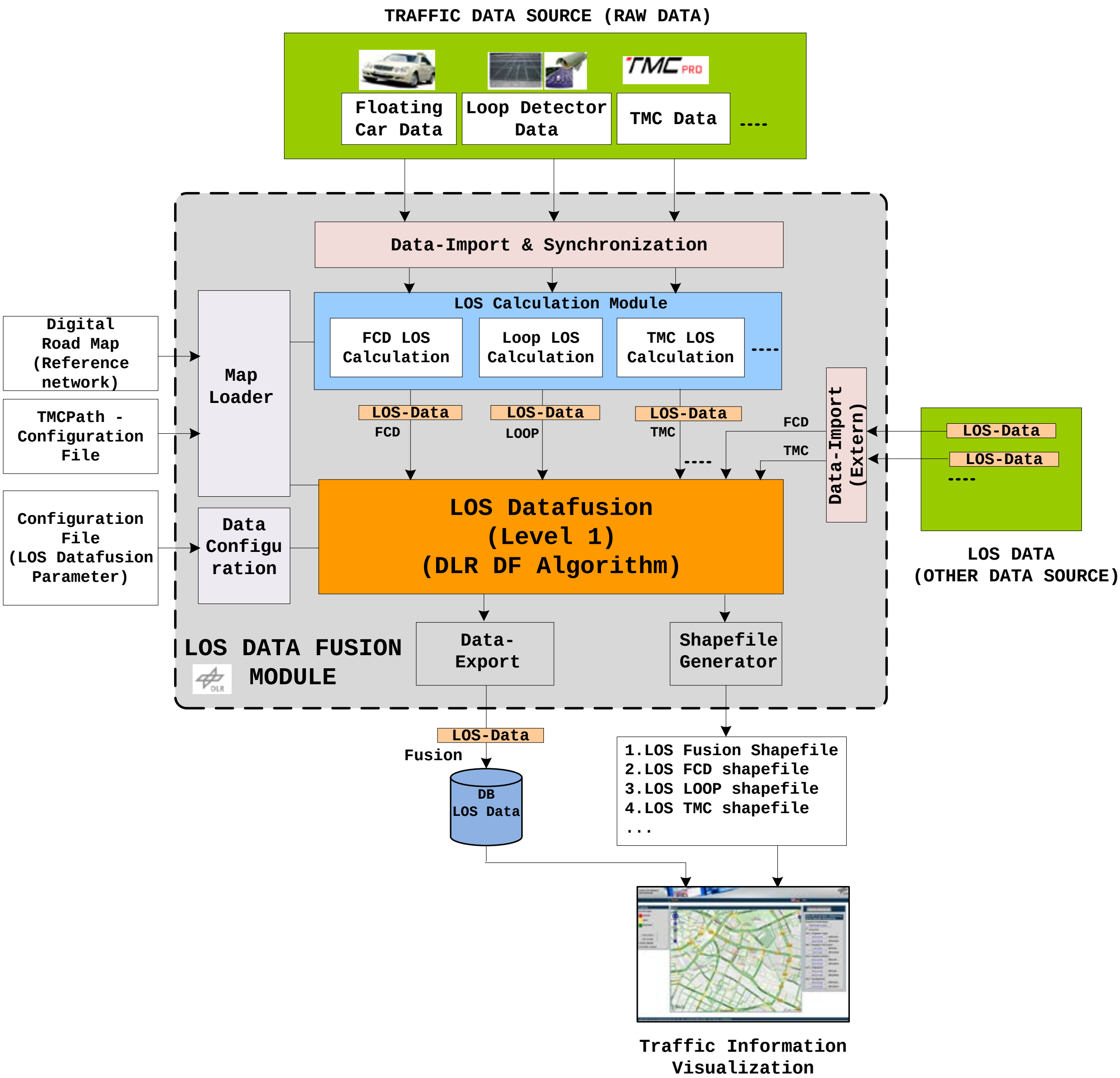


Figure 3: System architecture of the DLR-LOS data fusion module

Description of the system components

This section describes the most relevant components of the data fusion system in detail.

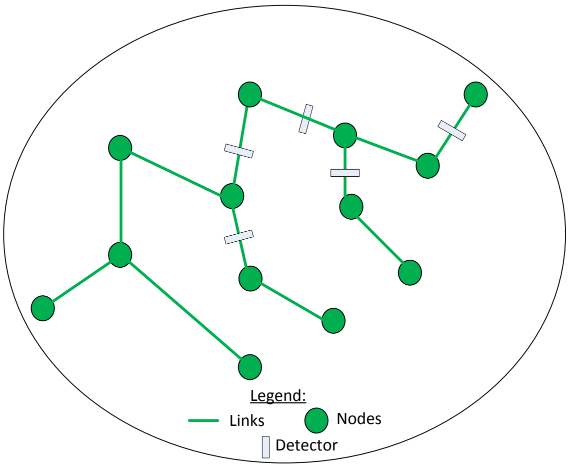
Map loader

A digital road map (e.g. NAVTEQ) is required for the LOS data fusion. It is load into the system as a reference road network (RN) and consists of nodes connected by links in the sense of a mathematical graph.

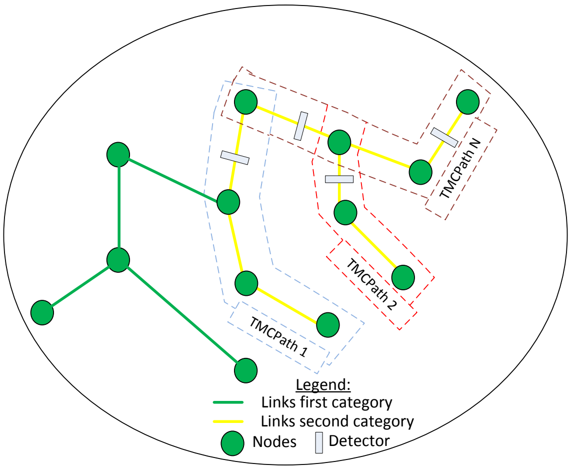
The links are the smallest geographic unit (see Figure 4a) to be considered in context of the data fusion. That means, the fused LOS values are allocated to each link of the road network.

Motivated by the concept of RDS-TMC[5], the realized LOS data fusion module allows multiple links of the reference network to be combined to a so-called TMC-path (see Figure 4b) where only one fused LOS value per TMC-path (instead of values for each single link) is provided.

a) RN without TMC-Paths



b) RN with TMC-Paths



c) Example of RN for the region Munich

Figure 4: Schematic illustration of different road network representations

The role of the "Map Loader" is to initialize both the reference network as well as the predefined TMC-paths contained in this network.

The links of the reference network are divided into two categories (see Figure 4b):

1. **First category:** all links of the network which are not part of any defined TMC-path.
2. **Second category**: all links of the network, which are part of at least one TMC-path.

The distinction between this two link categories is important because they are treated differently in the LOS data fusion. On links of the first category, the *link-oriented fusion* is applied (**vertical LOS fusion**) as presented in section “LOS data fusion module” below and based on the quality weighted median of the input data, while the *(optional) path-oriented* approach for links of the second category comprises additional spatial averaging over all links of the corresponding TMC-path (**horizontal fusion**).

The link-oriented as well as the path-oriented LOS data fusion are described in more detail below. Figure 4c shows the fully initialized road network with links of the first category (green) and links of the second category (yellow) for the exemplary region of Munich in Germany. On Figure 4c only the TMC-paths that contains at least one detector is visualized, otherwise the graphic should be more yellow. Of course, the user can choose whether the reference road network will be initialized with or without TMC-paths when starting the system.

Data import and synchronization

Depending on the type of available input data sources (e.g. FCD or detector), the raw data like speed, traffic volume, quality value, time stamp, unique link ID or the direct LOS-values corresponding to each link contained in the previously load reference network are periodically imported into the system via the data importer. After this process, the data are synchronized according to their timestamps in order to filter data older than some allowed configured fixed time (for example the current data time stamp must be not older than 5 minutes). In the case of raw data import the LOS value calculation (see the next paragraph) is required and after that the resulting LOS data can be forwarded to the data fusion. An overview of the distribution of the time stamp difference and the data volume (as related to the test region Munich) is illustrated in Figure 5.

(a) (b)

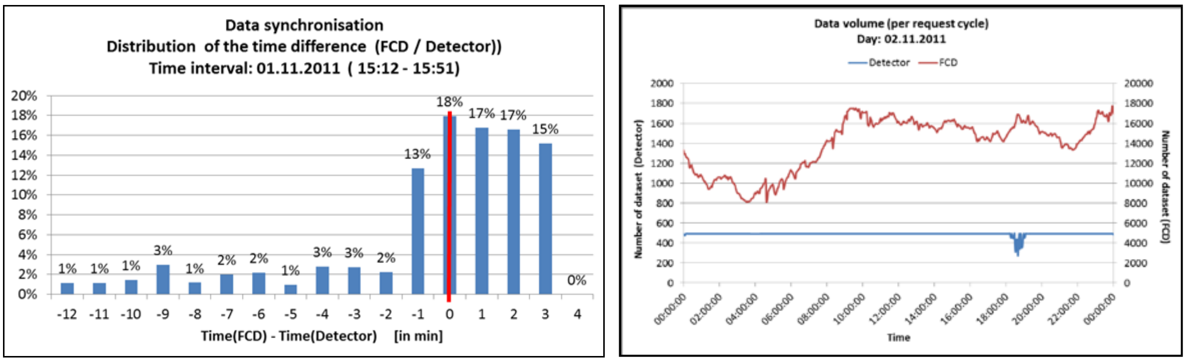


Figure 5: Example of distribution of the imported input data for the LOS -module.

LOS values calculation module

In the case of raw data import, LOS values for the single data sources need to be calculated. For this purpose, there are various methods named in the literature (cf. [1, 2]) which take several transportation aspects like the used traffic detection mode (e.g. FCD, detector) as well as the road category (e.g. highways, national road) and other parameters (e.g. travel speed, local speed, mean waiting time, traffic density) into account. The currently implemented LOS calculation in the DF-module uses the method as described in [1].

LOS data fusion module

The LOS data fusion algorithm as described in [3] does not distinguish between the original links of the reference network (first category) and links of TMC-paths (second category), which can be seen as links of a coarsened road network. In both cases, the same algorithm for the data fusion (**vertical LOS fusion**) is used. However, the calculation of path-based LOS values requires an additional spatial averaging over all edges belonging to the TMC path (**horizontal "fusion"**), which is preferably performed at the level of the raw data (**option 1**), but is also possible on the basis of the vertical LOS fusion values of the individual edges (**option 2**).

The implemented LOS data fusion module as a core component of the described system (see Figure 3) implements the actual vertical LOS fusion as well as the both variants of the horizontal "fusion" (option 1 and 2). The appendix illustrates the schematic overview about the vertical and horizontal fusion.

<u>A - Vertical LOS-data fusion</u>

The link- or path-based LOS values of each data source like FCD or detector with associated quality values are the basis for the vertical fusion. The fusion itself (including estimation of the quality of the results which is also called quality fusion) applies a quality-weighted median method as described in [3] and provides a LOS fusion value ($LOS_{Fusion}^{Link(i)}(t)$) and together with its estimated quality ($w_{Fusion}^{Link(i)}(t)$) for the corresponding link.

An example of the results delivered by the data fusion based on two data sources (FCD and loop detector) is shown in Figure 6.

```
datafusion : edgeId:576292593 Anzahl InputData:2
Input LOS: [LOOP,A,0,level:4, quality:0.98], [FCD,A,0,level:3, quality:1.0],
TransformedLOS: [LOOP,A,0,transformedLevel:6, transformedQuality:0.65333337], [FCD,A,0,transformedLevel:6, transformedQuality:0.5]
LOSFusion: [[LOOP, FCD],A,0,LevelFusion:6, qualityFusion:0.76657784]
---
```

Figure 6: Example of LOS data fusion results

The number of LOS-levels or scales for data fusion results is configurable and preferably depends on the number of LOS-levels of the data sources. As shown in Figure 6 before and after the data fusion, the LOS scale transformation may be required sometimes if the number of LOS-levels for input data (level-4 for detector and level-3 for FCD) is different to the one configured by the data fusion module (level-6). Regardless of that, it is recommended to avoid unnecessary transformations that can negatively affect the quality of the fusion results.

<u>B - Horizontal „Fusion“</u>

As mentioned above, there are two options to determine fused LOS values as well as associated quality fusion values in context of the TMC-path-based approach: the first one is based on the spatial averaging on raw data level (***Option 1***) and the second one on the basis of already link-based fused LOS-values (***Option 2***) which belong to the same TMC-path. The realized data fusion software module supports the both variants of the horizontal fusion as described in the following lines.

Option 1: Spatial averaging on the raw data level

At the level of the TMC paths, it is useful to calculate a weighted mean for traffic volumes *q* or average speed *v* from the link-based raw data (see equation (1)) for each data source separately without immediately assigning a level of service. This yields a kind of "path-based raw data".

In (1) and (2), L_j represents the length of the *j*-th link of the corresponding TMC-Path.

(1) $$q_{Source(k)}^{TMCPath(i)}(t) = \frac{\sum L_j \cdot q_{Source(k)}^{Link(j)}(t)}{\sum L_j} \quad \text{resp.} \quad v_{Source(k)}^{TMCPath(i)}(t) = \frac{\sum L_j \cdot v_{Source(k)}^{Link(j)}(t)}{\sum L_j}.$$

Quite similar to the calculation of path-related traffic volumes and speeds, the quality of the path based raw data can be guessed. Considering the supplied or estimated quality values of input data formula (2) is used in this case.

(2) $$w_{Source(k)}^{TMCPath(i)}(t) = \frac{\sum L_j \cdot w_{Source(k)}^{Link(j)}(t)}{\sum L_j}.$$

Based on the equations (1) and (2) the "path-based raw data" are available which can be processed completely analogously to the single link-oriented approach of the LOS data fusion. This includes the step of calculation of input LOS-values (see section related to the LOS calculation) from the previous obtained path based raw data as well as the vertical LOS data fusion on the level of TMC-paths.

Option 2: Spatial averaging on the link-based LOS data fusion

Unlike above, option 2 consists of the vertical fusion of available input LOS-data for each link belonging to the considered TMC-path (including the assessment of the quality of the results) in the first step. Then, the determination of the path based LOS-value uses the link length weighted average of the LOS values obtained from the previous step as depicted in equation (3), where L_j is the length of the *j*-th edge of the corresponding TMC-Path.

(3) $$LOS_{Fusion}^{TMCPath(i)}(t) = \frac{\sum L_j \cdot LOS_{Fusion}^{Link(j)}(t)}{\sum L_j}.$$

In the same way, the quality fusion for the selected TMC-path is done:

(4) $$w_{Fusion}^{TMCPath(i)}(t) = \frac{\sum L_j \cdot w_{Fusion}^{Link(j)}(t)}{\sum L_j}.$$

Finally, the appendix shows the overview of the integral structure of the LOS data fusion in its different variants.

Data Export

The results of the LOS data fusion are permanently stored in a data base. The “Data Export” component provides the appropriate data base interface for this.

Shape File Generator

As the name indicates, the task of this component is to generate corresponding shape files of the computed LOS data fusion values in order to visualize the fused LOS traffic information using suitable map viewer tools.

Visualisation of traffic information based on the LOS data fusion

The Cityrouter viewer software [4] as developed by DLR has been extended to support the visualization of traffic information based on the LOS-data fusion results.

Test case and results evaluation

In order to test the newly implemented LOS data fusion system, floating car data (FCD) of a taxi fleet consisting of about 2,700 vehicles and data from about 500 loop detectors in the region of Munich, Germany has been used. Table 1 illustrates the input LOS data constellation before scale transformation (b.T.).

Table 1: LOS input/output data constellation

	Data sources	**Number of LOS levels**	**LOS-categories (“/” = n.a.)**
Input data (2 sources)	LOS_FCD b.T.	3	A, B, C, /
	LOS_LOOP b.T.	4	A, B, C, D, /
	Data fusion	**Number of LOS levels**	**LOS-categories (“/” = n.a.)**
Output data	LOS_FUSION	4	A, B, C, D, /

Moreover, the following tables (see Table 2-5; a.T. = “after transformation”) shows in detail which data constellations (percentages) yield the named fusion result (A, B, C and D). We see the dominance of the detector data and the relatively high proportion of missing data (indicated through the symbol “/”). As can be seen, the implemented DF-module efficiently fills most of the gaps where data of one of the input data sources are missing.

Table 2: Detail results for LOS FUSION =A

LOS_FUSION = A		LOS_LOOP a.T.				
		A	B	C	D	/
LOS_FCD a.T.	A	**28.2%**	**0.0%**	**0.7%**	**0.0%**	**18.3%**
	B	**9.6%**	0.0%	0.0%	0.0%	0.0%
	C	**0.3%**	0.0%	0.0%	0.0%	0.0%
	D	**0.1%**	0.0%	0.0%	0.0%	0.0%
	/	**42.9%**	0.0%	0.0%	0.0%	0.0%

Table 3: Detail results for LOS FUSION =B

LOS_FUSION = B		LOS_LOOP a.T.				
		A	B	C	D	/
LOS_FCD a.T.	A	0.0%	**11.7%**	0.0%	0.0%	0.0%
	B	**0.3%**	**4.4%**	**0.6%**	**0.0%**	**49.3%**
	C	0.0%	**0.5%**	0.0%	0.0%	0.0%
	D	0.0%	**0.3%**	0.0%	0.0%	0.0%
	/	0.0%	**33.0%**	0.0%	0.0%	0.0%

Table 4: Detail results for LOS FUSION =C

LOS_FUSION = C		LOS_LOOP a.T.				
		A	B	C	D	/
LOS_FCD a.T.	A	0.0%	0.0%	**10.0%**	0.0%	0.0%
	B	0.0%	0.0%	**7.8%**	0.0%	0.0%
	C	**0.5%**	**0.0%**	**2.5%**	**0.0%**	**31.9%**
	D	0.0%	0.0%	**0.7%**	0.0%	0.0%
	/	0.0%	0.0%	**46.7%**	0.0%	0.0%

Table 5: Detail results for LOS FUSION =D

LOS_FUSION = D		LOS_LOOP a.T.				
		A	B	C	D	/
LOS_FCD a.T.	A	0.0%	0.0%	0.0%	**0.0%**	0.0%
	B	0.0%	0.0%	0.0%	**0.0%**	0.0%
	C	0.0%	0.0%	0.0%	**3.5%**	0.0%
	D	**0.0%**	**0.0%**	**0.0%**	**10.5%**	**86.0%**
	/	0.0%	0.0%	0.0%	**0.0%**	0.0%

Conclusion

This contribution introduces a new methodology using a quality-weighted median approach for efficiently and generically fusing LOS data from different sources and focuses on the technical aspects of the realization of LOS data fusion system as designed and implemented by DLR. The LOS-DF-module has been tested in the region of Munich, Germany. The first results show that the DF can be a suitable tool for systematically improving the quality of traffic information.

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Appendix

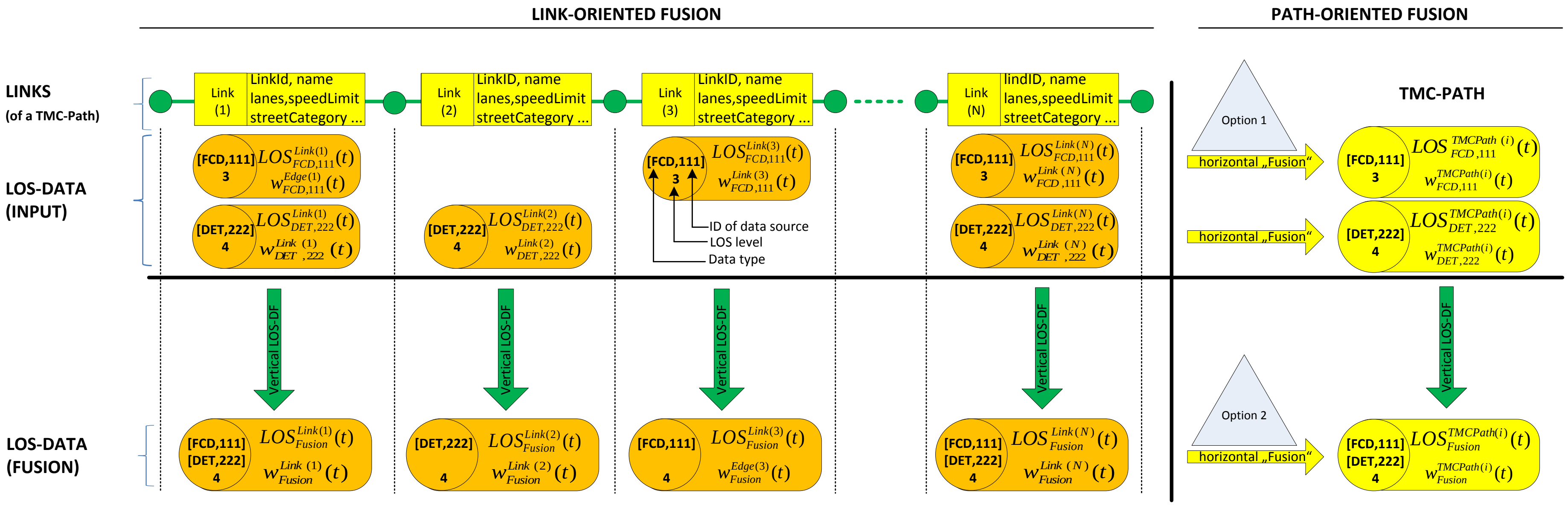

Figure 7: Vertical LOS data fusion and horizontal “fusion” with options 1 and 2