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BIM-GIS Interoperability for Highway Traffic Information Sharing

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Abstract: Information sharing is the main purpose of realizing interoperability between the application domains of Geographic Information System (GIS) and Building Information Modeling (BIM). This paper presents and describes the workflow of BIM-GIS interoperability for highway traffic information sharing. An innovative and automatic Dynamo process was presented to transfer the shapes and attributes of the shapefile from GIS to BIM. On the basis of the transformed BIM model, the detailed traffic data was added and expressed in the form of families and sheets to expand traffic information. Then, the shapes of the model were swept as solid geometries in the BIM environment applying Dynamo. The expanded BIM model was transferred back to the GIS system using the Industry Foundation Classes (IFC) scheme. The mutual communication between BIM and GIS was achieved based on Dynamo and IFC. This paper provides a convenient and feasible way to realize BIM-GIS interoperability for highway traffic information sharing according to the characteristics of highways in terms of graphic expression and model creation.

Key words: BIM, GIS, interoperability, highway traffic information

1. INTRODUCTION

The statewide traffic volume information in Indiana is embedded and displayed in a Geographic Information System (GIS) format as part of the Highway Performance Monitoring System (HPMS). As the main feature of the GIS system, shapefiles are used to exhibit traffic volumes with related highway locations and geometrics. The shapefiles in GIS, however, are not suitable for displaying complex structures and related objects because of their non-topological nature [1]. The current HPMS system includes the traffic information collected at selected sample locations across the state highway network. However, the detailed traffic data collected at the permanent traffic data recording stations, such as the Weigh-in-Motion (WIM) and Automatic Traffic Recorder (ATR) stations, is not included. In order to improve the traffic information system, the Building Information Modeling (BIM) platform was adopted to take advantage of BIM's versatile features and functions. BIM is a comprehensive life-cycle information management platform from design and planning to operation and maintenance. It integrates multi-disciplinary and multi-format data into one model to produce digital representations of buildings or infrastructures. In addition, BIM has a complete information hierarchy, from categories and subcategories to families and instances, to characterize the structures and relationships of objects in the model [2,3].

BIM-GIS interoperability and integration are often used for sharing and exchanging building data and elements. Barbato et al. [4] proposed a procedure to connect BIM with GIS. They concluded that the integrated BIM-GIS can reduce data storage fragmentation and improve data representation. Karan et al. [5] used semantic web technology to achieve semantic interoperability between BIM and GIS and constructed a new ontology to enhance data exchange and integration. Hbeich et al. [6] introduced semantic-based BIM-GIS interoperability approaches to checking the relationship and compliance of building elements with urban and construction rules. Jetlund et al. [7] developed a model to improve interoperability between BIM and GIS and indicated that core features and data from the two application domains can be linked. Zhu et al. [8] put forward an enhanced open-source approach for the integration of BIM and GIS and demonstrated that the method can facilitate data exchange between the two platforms. Ding et al. [9] presented a linguistic-based semantic mapping method and illustrated that data integration and exchange can be realized through text mining techniques. Based on the literature review, Dynamo, a visual programming tool, has been applied to building projects for model interaction, but rarely to highway projects. Buildings and highways have obvious differences in terms of graphic expression and model creation. In general, buildings are enclosed spaces with walls and roofs and are extruded as solids in the longitudinal direction. However, highways are outlined with open lines in the horizontal direction. Therefore, the existing Dynamo conversion methods used in building projects cannot be directly applied to highway projects for model interaction.

In this study, an innovative and automatic Dynamo process was presented to transfer the shapes and attributes of the shapefiles from GIS to BIM. The traffic attributes were expanded in the BIM model to include vehicle types, speeds, and axle weights. The expanded BIM model was transferred back to the GIS system using the Industry Foundation Classes (IFC) scheme to verify BIM-GIS interoperability. The mutual communication between BIM and GIS was achieved through Dynamo and IFC. This paper presents the model conversion processes between BIM and GIS and describes the convenient and feasible way to realize BIM-GIS interoperability for highway traffic information sharing.

2. CONVERSION PROCESS FROM GIS TO BIM

Family is the core and most basic unit of BIM modeling. Families can not only express any component shapes but also store component attributes in form of parameters. Families can also be related to each other by setting rules in properties [10]. Highway models in the shapefile format are represented by Poly-Curves and each Poly-Curve associates with a specific road segment information stored in an attribute table. In order to convert the complete shapefile model into the BIM platform, families must be deployed during the conversion process. The whole process consists of two parts. One part is to create shape families in a family template, and the other is to place the families in a project template to build the highway BIM model. The five key steps of the conversion process are described below:

Step 1: Set Coordinate System. Since both GIS and BIM support the Projected Coordinate System (PCS), the PCS is used as the coordinate system for the model conversion. The origin point (0,0) is selected as a reference for measuring distances and positioning objects. The center point of the highway GIS model is moved to the origin so that the highway BIM model can be generated using the same origin.

Step 2: Import Shapes. Poly-Curves are used in GIS to represent shapes of road segments. However, Poly-Curves cannot be directly imported into the BIM family template. Thus, Poly-Curves have to be extracted as a series of points and then the points can form Nurbs-Curves to replace the original Poly-Curves. The formed Nurbs-Curves can then be transformed into BIM compatible Model-Curves. Each Model-Curve is treated as a separate individual and saved as a road segment family.

Step 3: Import Attributes. The GIS model contains a table of road segment attributes. There are 26 attributes related to traffic information, including annual average daily traffic, D factors, and K factors. The attribute values, with assigned names, are exported from the GIS model and are utilized as family parameters in the BIM model.

Step 4: Save as Families. Road segment families with the 26 pre-defined parameters are generated under the PCS in the family template. As every road segment has a GIS-system-managed number, FID, which uniquely identifies a record or feature, the family file can be named by the FID number and then saved. A generic BIM model can be built based on these road segment families.

Step 5: Load & Place Families. All families can be loaded into the BIM project template. Because the center point of the PCS of the GIS model has been moved to the origin, the road segment families have to be placed with the origin as the placement point. The original structure of the network of roadways will remain unchanged in the produced BIM model.

Step 1 through Step 4 are used to create shape families, and Step 5 is used to place the created families to build the highway BIM model. Extra steps are also applied to aid the conversion process, such as the task dialog step and the screen cleanup step. The complete conversion process is shown in Figure 1. The steps can be achieved in the Dynamo environment automatically.

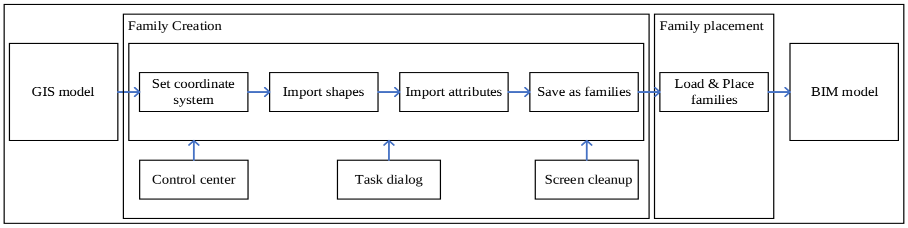
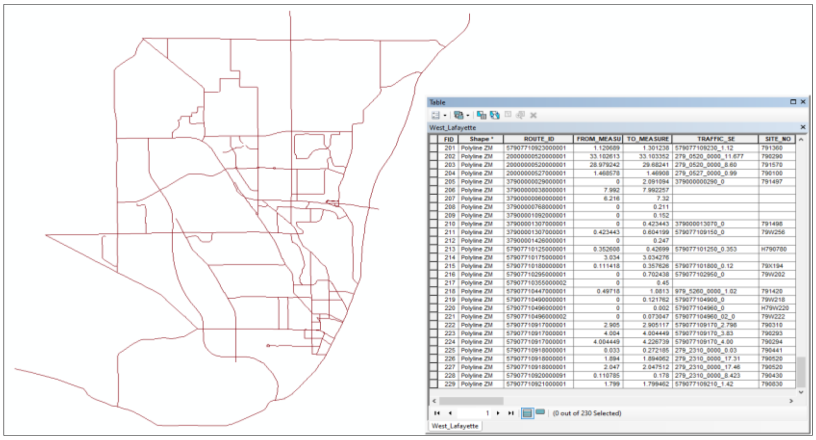


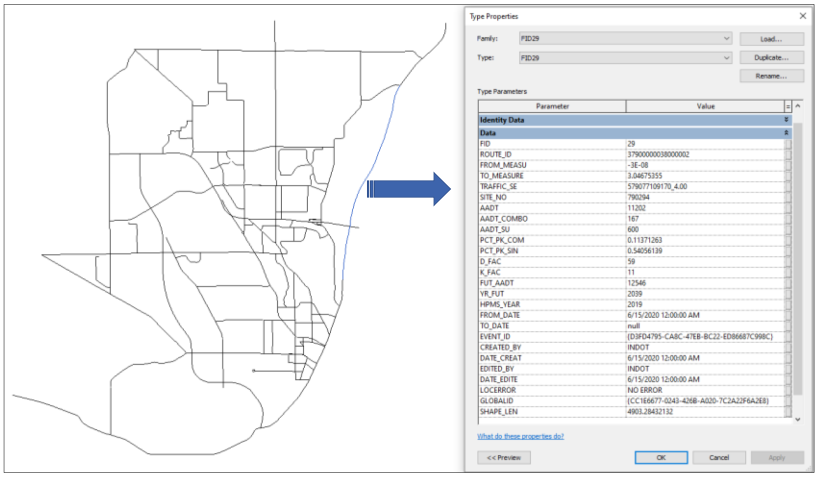
Figure 1. Conversion process

A local area traffic database was used to demonstrate the conversion process. The highway GIS model of the West Lafayette area is shown in Figure 2. The model includes road segments represented by Poly-Curves and a traffic information attribute table. Each Poly-Curve associates with a specific road segment information stored in the table. The highway BIM model, as shown in Figure 3, was transformed from the GIS model through the five steps. The BIM model treats every road segment as a family with the attribute information of the road segment as parameters.



FID	Shape *	ROUTE_ID	FROM_MEASU	TO_MEASURE	TRAFFIC_SE	SITE_NO
201	Polyline ZM	579077109230000001	1.120689	1.301238	579077109230_1.12	791360
202	Polyline ZM	200000005200000001	33.102613	33.103352	279_0520_0000_11.677	790290
203	Polyline ZM	200000005200000001	28.979242	29.68241	279_0520_0000_8.60	791570
204	Polyline ZM	200000005270000001	1.468578	1.46908	279_0527_0000_0.99	790100
205	Polyline ZM	379000000290000001	0	2.091094	379000000290_0	791497
206	Polyline ZM	379000000380000001	7.992	7.992257		
207	Polyline ZM	379000000600000001	6.216	7.32		
208	Polyline ZM	379000007680000001	0	0.211		
209	Polyline ZM	379000010920000001	0	0.152		
210	Polyline ZM	379000013070000001	0	0.423443	379000013070_0	791498
211	Polyline ZM	379000013070000001	0.423443	0.604199	579077109150_0	79W256
212	Polyline ZM	379000014260000001	0	0.247		
213	Polyline ZM	579077101250000001	0.352608	0.42699	579077101250_0.353	H790780
214	Polyline ZM	579077101750000001	3.034	3.034276		
215	Polyline ZM	579077101800000001	0.111418	0.357626	579077101800_0.12	79X194
216	Polyline ZM	579077102950000001	0	0.702438	579077102950_0	79W202
217	Polyline ZM	579077103550000002	0	0.45		
218	Polyline ZM	579077104470000001	0.49718	1.0813	979_5260_0000_1.02	791420
219	Polyline ZM	579077104900000001	0	0.121762	579077104900_0	79W218
220	Polyline ZM	579077104960000001	0	0.002	579077104960_0	H79W220
221	Polyline ZM	579077104960000002	0	0.073047	579077104960_02_0	79W222
222	Polyline ZM	579077109170000001	2.905	2.905117	579077109170_2.796	790310
223	Polyline ZM	579077109170000001	4.004	4.004449	579077109170_3.83	790293
224	Polyline ZM	579077109170000001	4.004449	4.226739	579077109170_4.00	790294
225	Polyline ZM	579077109180000001	0.033	0.272185	279_2310_0000_0.03	790441
226	Polyline ZM	579077109180000001	1.894	1.894062	279_2310_0000_17.31	790520
227	Polyline ZM	579077109180000001	2.047	2.047512	279_2310_0000_17.46	790520
228	Polyline ZM	579077109200000091	0.110785	0.178	279_2310_0000_8.423	790430
229	Polyline ZM	579077109210000001	1.799	1.799462	579077109210_1.42	790830

Figure 2. Highway GIS model



Parameter	Value
Identity Data	
Data	
FID	29
ROUTE_ID	37900000038000002
FROM_MEASU	-3E-08
TO_MEASURE	3.04675355
TRAFFIC_SE	579077109170_4.00
SITE_NO	790294
AADT	11202
AADT_COMBO	167
AADT_SU	600
PCT_PK_COM	0.11371263
PCT_PK_SIN	0.54056139
D_FAC	59
K_FAC	11
FUT_AADT	12546
YR_FUT	2039
HPMS_YEAR	2019
FROM_DATE	6/15/2020 12:00:00 AM
TO_DATE	null
EVENT_ID	{D3FD4795-CA8C-47EB-BC22-ED86687C998C}
CREATED_BY	INDOT
DATE_CREAT	6/15/2020 12:00:00 AM
EDITED_BY	INDOT
DATE_EDITE	6/15/2020 12:00:00 AM
LOCERROR	NO ERROR
GLOBALID	{CC1E6677-0243-426B-A020-7C2A22F6A2E8}
SHAPE_LEN	4903.28432132

Figure 3. Highway BIM model

3. INFORMATION EXPANSION

Vehicles are classified into 13 classes, in which Class 1 through Class 3 vehicles are lightweight vehicles and Class 4 through Class 13 vehicles are heavyweight vehicles (buses or trucks) [11]. Currently, 93 Automatic Traffic Recorder (ATR) stations and 63 Weigh-In-Motion (WIM) stations are under service to continuously collect the traffic data of passing vehicles in the Indiana highway network [12]. To improve highway traffic information management, the traffic characteristics from ATR and WIM stations must be stored, represented, and managed in the transformed highway BIM model. The traffic data recorded in the ATR station on US 52 in West Lafayette was processed to illustrate in the BIM model. The 13 typical vehicle families were built to characterize their respective features as depicted in Figure 4. The vehicles in Figure 4 include three groups: the multi-trailer vehicles in the top row (Classes 11, 12, and 13), the single-trailer vehicles in the middle row (Classes 8, 9, and 10), and the single-unit vehicles in the bottom row (Classes 1 through 7). The traffic characteristics are stored in the BIM model in terms of family types. The family type information is illustrated in Figure 5 using Class 7 vehicles as an example. The parameter values, including the average axle spacing, the average number of axles, Average Annual Daily Traffic (AADT), and Average Monthly Daily Traffic (AMDT), are stored and displayed in the model as indicated in Figure 5. In addition to the vehicle families, other key information, such as the location of the ATR station, can be easily included in the BIM model to describe the overall traffic characteristics.

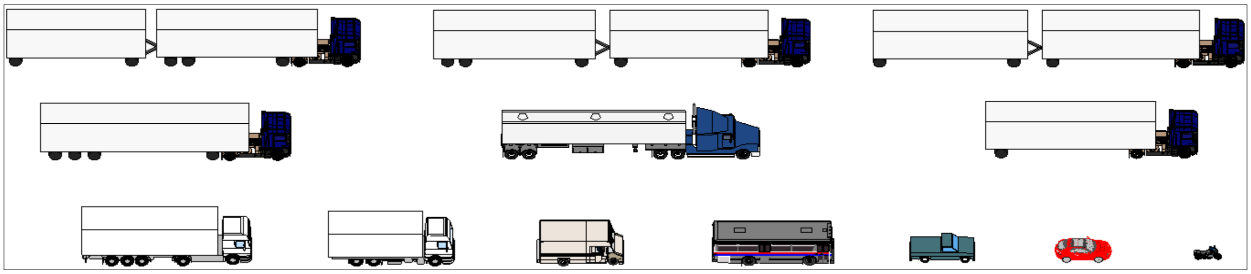
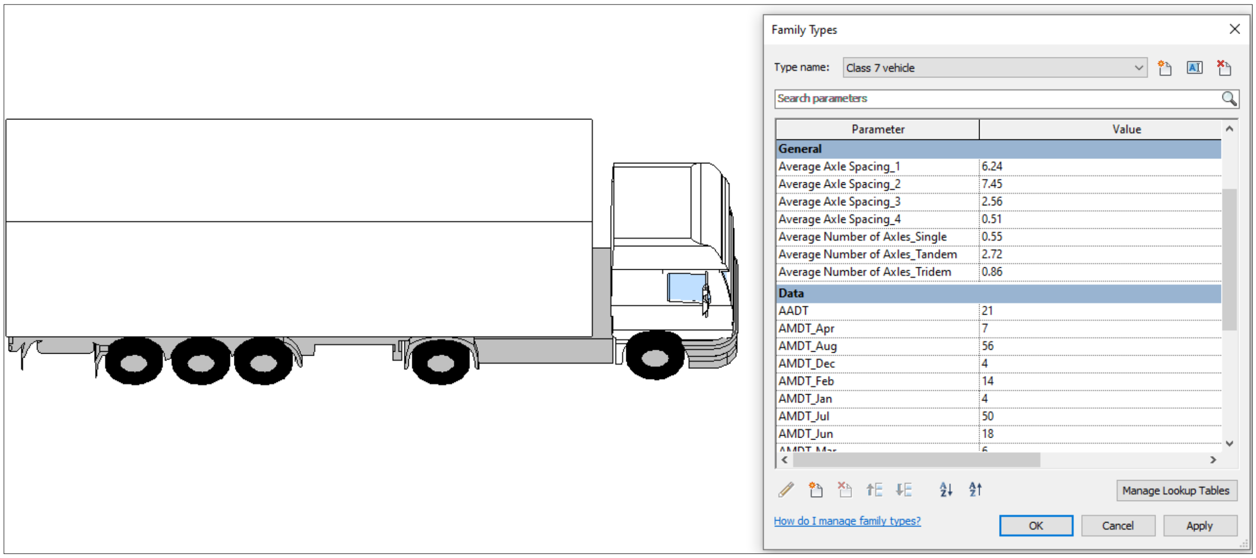


Figure 4. Vehicle families



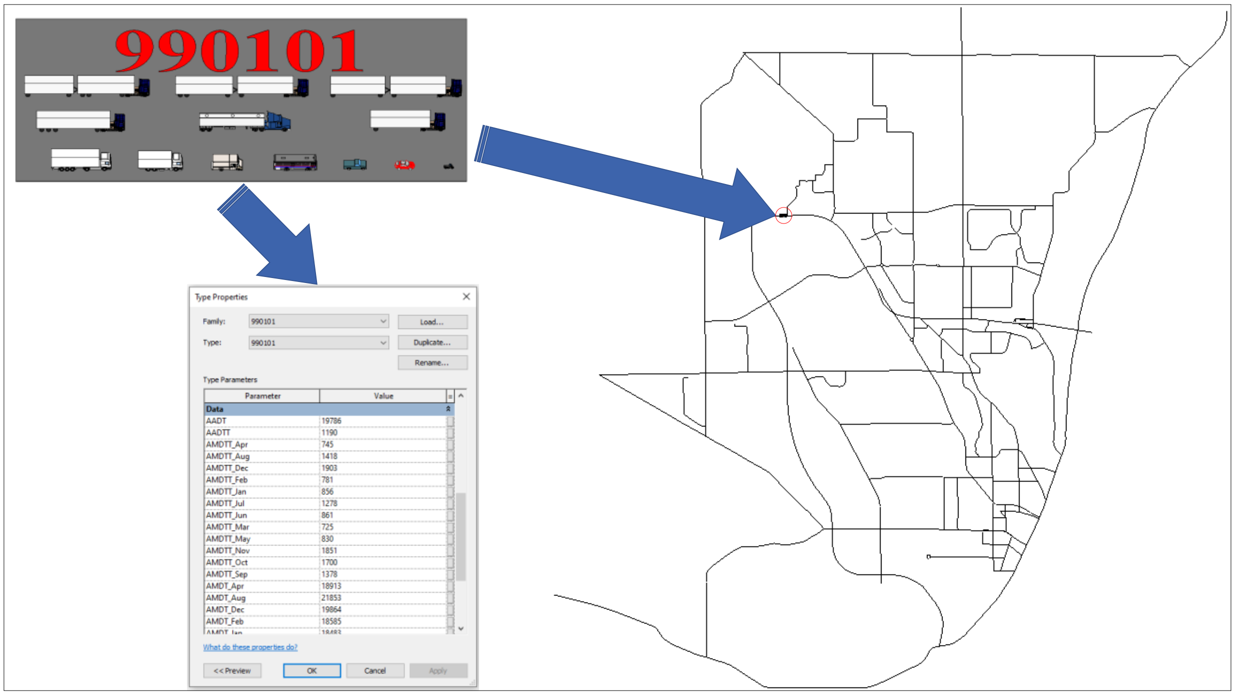
Family Types

Type name: Class 7 vehicle

Parameter	Value
General	
Average Axle Spacing_1	6.24
Average Axle Spacing_2	7.45
Average Axle Spacing_3	2.56
Average Axle Spacing_4	0.51
Average Number of Axles_Single	0.55
Average Number of Axles_Tandem	2.72
Average Number of Axles_Tridem	0.86
Data	
AADT	21
AMDT_Apr	7
AMDT_Aug	56
AMDT_Dec	4
AMDT_Feb	14
AMDT_Jan	4
AMDT_Jul	50
AMDT_Jun	18

Figure 5. Family type information of Class 7 vehicles

The station family is composed of the 13 typical vehicle families and can be automatically placed in the model by Dynamo. The characteristics of the overall traffic flow, such as AADT, AMDT, Average Annual Daily Truck Traffic (AADTT), and Average Monthly Daily Truck Traffic (AMDTT), can be stored into the BIM model. Figure 6 shows the location, style, and associated information of the ATR station. Sheets were created in the BIM model so that the BIM model could also present the traffic information in Visual Communication Design (VCD) in addition to in text form. Figure 7 shows a presentation of annual traffic in the form of tables and images. As can be seen from the figure, Class 2 vehicles accounted for the highest proportion followed by Class 3 vehicles. In addition, Class 5 vehicles were the most common trucks followed by Class 9 vehicles.



Type Properties

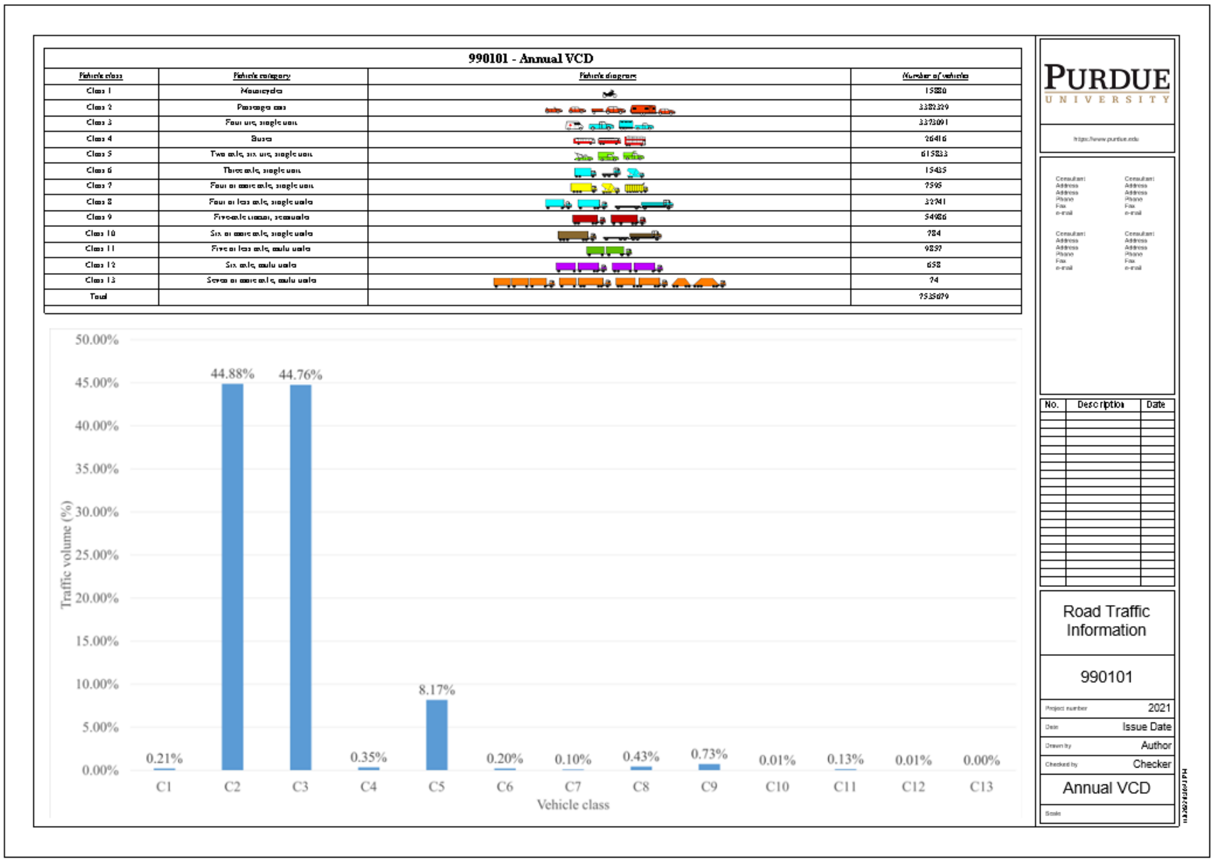
Family: 990101

Type: 990101

Type Parameters

Parameter	Value
Data	
AADT	19786
AADTT	1190
AMDTT_Apr	745
AMDTT_Aug	1418
AMDTT_Dec	1903
AMDTT_Feb	781
AMDTT_Jan	856
AMDTT_Jul	1278
AMDTT_Jun	861
AMDTT_Mar	725
AMDTT_May	830
AMDTT_Nov	1851
AMDTT_Oct	1700
AMDTT_Sep	1378
AMDT_Apr	18913
AMDT_Aug	21853
AMDT_Dec	19864
AMDT_Feb	18585
AMDT_Jan	18483

Figure 6. Station family



990101 - Annual VCD			
Vehicle class	Vehicle category	Vehicle diagram	Number of vehicles
Class 1	Motorcycles		15880
Class 2	Passenger cars		3382329
Class 3	Four tire, single unit		3373091
Class 4	Buses		26416
Class 5	Two axle, six tire, single unit		615833
Class 6	Three axle, single unit		15435
Class 7	Four or more axle, single unit		7595
Class 8	Four or less axle, single trailer		32741
Class 9	Five-axle tractor, semitrailer		54986
Class 10	Six or more axle, single trailer		784
Class 11	Five or less axle, multi trailer		9857
Class 12	Six axle, multi trailer		658
Class 13	Seven or more axle, multi trailer		74
Total			7535079

Road Traffic Information

990101

Project number	2021
Date	Issue Date
Drawn by	Author
Checked by	Checker

Annual VCD

Scale

Figure 7. Annual traffic distribution

4. REVERSE PROCESS FROM BIM TO GIS

IFC is an international standard for data exchange and sharing across different software. IFC provides a kind of template for mapping elements from proprietary file formats to open file formats as entities according to the structure of semantics. For example, if a door needs to be transferred from a BIM file to a GIS file, the category of the door has to be mapped to the IfcDoor entity in the IFC scheme. The IFC file of entities is an open format file and can be read by the GIS software. IFC has released several versions of schemes, such as IFC 2x and IFC 4. The most widely used scheme is the IFC 2x3 scheme. Thus, the IFC 2x3 scheme is chosen to transfer the expanded highway BIM model back to the GIS system. The reverse process is summarized below:

Step 1: Sweep Families as Solids. The shape types of the highway model have been changed from Poly-Curves to Model-Curves in the BIM environment. However, Model-Curves are not solid geometries, which cannot be identified by the IFC scheme. Therefore, Model-Curves must be swept as solids. The sweeping programming is shown in Figure 8. Two groups are created to complete the sweeping process, including the *Generate solid geometries* group and the *Save as families* group. The swept families and the ATR station family are formed a solid highway BIM model.

Step 2: Map Categories to Entities & Import to GIS. The IFC 2x3 scheme includes 1104 entities with different type enumerations. However, the scheme lacks traffic-related entities. Hence, the IfcBuildingElementProxy entity is selected to map the object categories in the highway BIM model. An IFC file is then generated based on the BIM model, and the properties of the elements are also contained in the file. GIS system has data interoperability tools that can input and read the IFC file. Both shapes and properties of the expanded highway BIM model were imported to the GIS system.

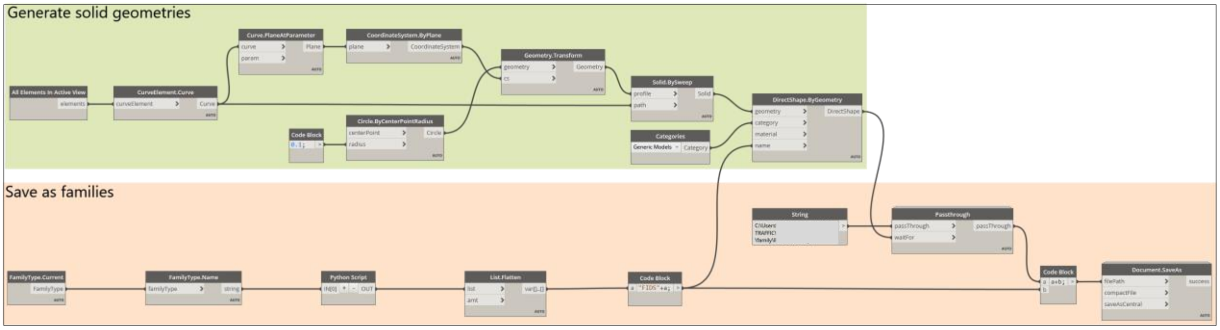


Figure 8. Family sweeping programming

Figure 9 shows the highway model in the GIS system. As can be seen from the figure, the shapes and properties of the model are transferred from BIM back to GIS successfully. The layout of the model remains the same after the reverse conversion, and the traffic information, including the inherent information from the road network as well as the added information from the ATR station, is saved in the attribute table. However, limited by the model expression ability, the distributions of annual, monthly, weekly, daily, hourly, and directional traffic in the form of VCD cannot be visually presented in the GIS model.

Figure 9. Updated GIS model

5. CONCLUSIONS

In this study, a workflow was developed to establish the BIM-GIS interoperability for highway traffic information sharing. According to the characteristics of highways in terms of graphic expression and model creation, Dynamo was employed to transfer the shapes and attributes of the shapefile from GIS to BIM. An innovative and automatic Dynamo conversion process was proposed and utilized. Poly-Curves were extracted and transformed into BIM compatible Model-Curves. Shape families were then established to characterize the corresponding attributes. On the basis of the transformed BIM model, traffic features recorded at an ATR station were characterized in the model in the form of families and sheets to expand traffic information. Then, the shapes of the highway model were swept as solid geometries in the BIM environment for the reverse conversion. The expanded BIM model was transferred back to the GIS system using the IFC scheme. The mutual communication between BIM and GIS was achieved through Dynamo and IFC. The result of this study provides a convenient and feasible way to realize BIM-GIS interoperability for highway traffic information sharing.

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