1. The Imperial Government of the United Barons of Aggression (IGUBA) has many employees, including President Felonios the III himself, and a vast network of spies reaching throughout all constituent provinces of the IGUBA. The council heads of IGUBA require a well-designed DBMS to organize and control their employees and spies. The relevant information concerning the inner workings of IGUBA is as follows:

- Each spy is a government employee and so has a clearance level (low, intermediate, high, top), a name, and a unique registration number. In addition, each spy currently resides in a specific province, which may or may not be his or her province of expertise (see below).
- Felonios the III is spying on all provinces in the IGUBA. Each province has a status (friend-of-the-empire, watch-closely, enemy-at-large) and a unique name.
- A number of high tech devices are available to each spy depending on their mission. These devices have a name, a classification (weapon, surveillance, transportation, general), and an inventor. Each device is associated with a particular mission (see below) and self-destructs once that mission is terminated. Together with the mission number, the name of the device uniquely identifies it.
- Each spy is an expert on one or more provinces and his or her expertise may overlap with other spies.
- Spies 40 or older (“senior spies”) must have an annual medical exam. It is required to store the date of the most recent exam for these spies.
- Spies under 40 (“junior spies”) must have an annual psychiatric evaluation. It is required to store the date of the most recent evaluation for these spies.
- Every junior spy must have at least one supervisor; all supervisors of junior spies must be senior spies.
- Every senior spy has exactly one supervisor; all supervisors of senior spies must be government employees who are not themselves spies (and may be the president himself).
- The president’s office has a number of ongoing missions that spies may be assigned to. Each mission has a unique mission number, a name, and a minimum number of spies involved. Each mission involves spying on one or more provinces of the IGUBA.

- From time to time, the president requires the spies participate in mission briefings. For each such briefing, the date, number of days so far on the mission, and mission status (satisfactory, stalled, terminated) must be recorded. Each briefing event is uniquely identified by the date on which it occurred and the mission number. Both spies and government employees may attend mission briefings.

Given this information, your tasks are the following.

(a) Design and draw an ER diagram for the IGUBA database. Be sure to indicate the various attributes of each entity and relationship set (with associated domains); also specify a primary key for each entity set and any participation constraints for each relationship set. Specify overlap and covering constraints as well (in English). Make sure you include weak entities and class hierarchies in your diagram where appropriate. Do not use aggregation in your diagram. If you make assumptions that are not part of the requirements specification above, state these clearly and briefly justify them.

Solution: An example of an ER diagram showing all constraints given above is shown in figure 1 (page 3). Note: this is not the only possible solution to this problem. If you have a different diagram, it is still possible to receive full credit for this question.

(b) Translate your ER diagram into tables using SQL-92 CREATE TABLE statements assuming the following additional constraint not present in the diagram: there must be at least one employee who is not a spy present at each mission briefing. (This employee may differ from mission briefing to mission briefing.) You should attempt to capture this constraint within the CREATE TABLE command itself instead of modifying the ER diagram and then translating the modified diagram. Be sure to read §3.5 of your text (pages 66-75) carefully before attempting this. In particular, when you make a decision concerning tabular representation (such as whether a relationship set should be represented as a separate table or not, and how a class hierarchy should be translated), briefly justify your decision. Make sure you specify primary and foreign key constraints. You may ignore participation constraints, alternate candidate keys and domain restrictions for the purposes of this translation. If you make assumptions that are not part of the requirements specification above, state these clearly and briefly justify them.

Solution: The SQL-92 CREATE TABLE statements follow. Additional assumptions / design decisions made:

- As stated in the diagram, we assume every government employee is either a spy or an employee. However, since any government employee may partici-
Overlap Constraints:

- Employee and Spy do not overlap
- Junior Spy and Senior Spy do not overlap

Cover Constraints:

- Employee and Spy cover IGUBA Members
- Junior Spy and Senior Spy cover Spy
pate in the “attend briefing” relation, we will translate the sets “Government Employee”, “Spy” and “Other Employee” separately.

- Similarly, since the three “Spy” entity sets each participate in a separate relation, we will have three separate tables for “Spy”, “Junior Spy” and “Senior Spy”.
- Supervisors of senior spies are listed along with the senior spies, since there is a unique supervisor for each senior spy.
- Weak entities are listed in the same table with their defining relationships.
- Assume identification numbers are integers and names/strings are no longer than 50 characters long.
- We will capture the additional constraint by making the “attend briefing” relationship a ternary one between Spy, Other Employee, and Briefing Event / briefing for. Then we will specify that the Other Employee field must be “NOT NULL”. This will force at least one employee who is not a spy to be present at each mission briefing.
  Technically, this modification obviates the need for a separate “Government Employee” table (since now no separate relationships involve it), but we will keep that table so as not to repeat attributes in the Spy and Other Employee tables.

CREATE TABLE Government_Employee
  ( registration_number INTEGER,
    clearance_level CHAR(50),
    name CHAR(50),
    PRIMARY KEY (registration_number) )

CREATE TABLE Other_Employee
  ( registration_number INTEGER,
    PRIMARY KEY (registration_number),
    FOREIGN KEY (registration_number) REFERENCES IGUBA_Member )

CREATE TABLE Spy
  ( registration_number INTEGER,
    age INTEGER,
    PRIMARY KEY (registration_number),
    FOREIGN KEY (registration_number) REFERENCES IGUBA_Member )

CREATE TABLE Junior_Spy
  ( registration_number INTEGER,
    medical_exam_date DATE,
    PRIMARY KEY (registration_number),
    FOREIGN KEY (registration_number) REFERENCES Spy )
CREATE TABLE Senior_Spy
  ( registration_number INTEGER,
    psych_eval_date DATE,
    sup_registration_number INTEGER,
    PRIMARY KEY (registration_number),
    FOREIGN KEY (registration_number) REFERENCES Spy,
    FOREIGN KEY (sup_registration_number) REFERENCES Employee )

CREATE TABLE Province
  ( name CHAR(50),
    status CHAR(50),
    PRIMARY KEY (name) )

CREATE TABLE Mission
  ( name CHAR(50),
    mission_number INTEGER,
    min_spies_involved INTEGER,
    PRIMARY KEY (mission_number) )

CREATE TABLE High_Tech_Device/available_for
  ( name CHAR(50),
    mission_number INTEGER,
    classification CHAR(50),
    inventor CHAR(50),
    PRIMARY KEY (mission_number, name),
    FOREIGN KEY (mission_number) REFERENCES Mission )

CREATE TABLE Briefing_Event/briefing_for
  ( date DATE,
    mission_number INTEGER,
    mission_length_in_days INTEGER,
    mission_status CHAR(50),
    PRIMARY KEY (date, mission_number),
    FOREIGN KEY (mission_number) REFERENCES Mission )

CREATE TABLE attend_briefing
  ( mission_number INTEGER,
    date DATE,
    spy_registration_number INTEGER NOT NULL,
    emp_registration_number INTEGER NOT NULL,
    PRIMARY KEY (mission_number, date, registration_number),
    FOREIGN KEY (mission_number, date)
REFERENCES Briefing_Event/briefing_for,
FOREIGN KEY (spy_registration_number) REFERENCES Spy,
FOREIGN KEY (emp_registration_number) REFERENCES Employee )

CREATE TABLE spy_on
( mission_number INTEGER,
  province_name CHAR(50),
  PRIMARY KEY (mission_number, province_name),
  FOREIGN KEY (mission_number) REFERENCES Mission,
  FOREIGN KEY (province_name) REFERENCES Province (name) )

CREATE TABLE assigned_to
( spy_registration_number INTEGER,
  mission_number INTEGER,
  PRIMARY KEY (spy_registration_number, mission_number),
  FOREIGN KEY (spy_registration_number)
    REFERENCES Spy (registration_number),
  FOREIGN KEY (mission_number) REFERENCES Mission )

CREATE TABLE resides_in
( spy_registration_number INTEGER,
  province_name CHAR(50),
  PRIMARY KEY (spy_registration_number, province_name),
  FOREIGN KEY (spy_registration_number)
    REFERENCES Spy (registration_number),
  FOREIGN KEY (province_name) REFERENCES Province (name) )

CREATE TABLE expert_on
( spy_registration_number INTEGER,
  province_name CHAR(50),
  PRIMARY KEY (spy_registration_number, province_name),
  FOREIGN KEY (spy_registration_number)
    REFERENCES Spy (registration_number),
  FOREIGN KEY (province_name) REFERENCES Province (name) )

CREATE TABLE spy_supervises_spy
( junior_spy INTEGER,
  senior_spy INTEGER,
  PRIMARY KEY (junior_spy, senior_spy),
  FOREIGN KEY (junior_spy) REFERENCES Junior_Spy,
  FOREIGN KEY (senior_spy) REFERENCES Senior_Spy )

(c) President Felonios thinks it is a good idea to decree that all spies assigned to
a mission must be experts on at least one province that the mission involves spying on. Can you express this constraint in your ER diagram without using aggregation? Briefly explain your answer.

Solution: This constraint applies to individual spies, missions and provinces, rather than to the whole entity sets. For example, consider the Spy entity set. Each spy is an expert on at least one province, and a spy may be an expert on several different provinces. Suppose spy number 008 is the only expert on the province of Meerton. This means that every mission that involves spying on Meerton would need to include spy 008. Even if we decomposed the Spy entity set into a hierarchy and spy 008 was in a separate class, there is no way to ensure the province name (in the “spy on” or “assigned to” relationship) is Meerton, unless we similarly decompose the Province entity set into “Meerton” plus other provinces. This method is infeasible in an ER diagram in general: a separate class would be needed for each spy and province. ER diagrams generalize individual entities into entity sets. Constraints of this type between individual entities may be better handled in SQL using triggers (we’ll see these later in the course) if aggregation is disallowed.

2. Figure 3 (page 15) shows an ER diagram for the conceptual design of a database containing information for a city works department (this department oversees the installation and maintenance of city utilities: power, roads, water, and trash). Answer the following questions based on this ER diagram.

(a) Extract an appropriate requirements specification from figure 3. Your specification should be in point form and should indicate the entity sets and relationship sets included in the diagram as well as their attributes and primary keys, and appropriate constraints (primary key constraints, participation constraints). You should clearly identify weak entities and their identifying relationship sets. You should also clearly state how class hierarchies are used to classify entity sets in the diagram. You need not be excessively wordy or prosaic in your answer; a similar question is answered in the solutions to the Fall 2000 assignment 1. The solution to that question should be your prototype.

Solution:
- Entity sets:
  - A \textit{Power Plant} has a unique plant number (the primary key), a current age, a maximum age, a capacity (measured in MW-h/month), and a type (gas, coal, nuclear, or solar).
  - A \textit{Water Structure} has a unique structure number (the primary key), a current age, a maximum age, a capacity (measured in m$^3$/month), and a type (pumping station, water treatment, desalination).
  - A \textit{Garbage Structure} has a unique structure number (primary key), a current age, a maximum age, a capacity (measured in tons/month), and a type (landfill, incinerator, recycling center).
- A Zone has a unique zone number (primary key), and a total amount of trash it produces (measured in tons/month).
- A Building is associated with a particular zone (in virtue of being located within that zone, which is the defining relationship for this entity set so that every building appears in exactly one zone) and together a building number and zone number make a primary key for this weak entity set. Additionally, each building has a power consumption (measured in MW·h/month) and a water consumption (measured in m³/month).
- There are three types of zones: Residential, Commercial, and Industrial. Each inherits the attributes from the Zone entity set. Additionally, each commercial zone has an average land value, each residential zone has a number reflecting its population, and each industrial zone has an average pollution level.
- A Road has a unique ID number (primary key), and a type (highway or local). Additionally, for each road, the date of the last maintenance and the date of the last resurfacing for that road is maintained (as attributes).

- Relationship sets:
  - Every building must be powered by at least one power plant.
  - Every building must be served by at least one water structure.
  - Every zone must have its trash removed to exactly one garbage structure. Furthermore, the number of the truck that ships the garbage for the zone is stored with this relationship.
  - For each residential zone, at least one road must connect it to some commercial zone.
  - For each residential zone, at least one road must connect it to some industrial zone.
  - For each commercial zone, at least one road must connect it to some residential zone.
  - For each commercial zone, at least one road must connect it to some industrial zone.
  - For each industrial zone, at least one road must connect it to some residential zone.
  - For each industrial zone, at least one road must connect it to some commercial zone.
  - Roads running between zones allow symmetric traffic flow; thus one road may satisfy two of the above constraints.

(b) The following tables detail a potential instance of the city works database. Identify all constraints arising from the ER diagram in figure 3 that are violated within this instance. For each constraint, suggest a solution that involves adding a minimal number of tuples or else deleting one tuple. Make sure you account for foreign key
constraints arising from the natural translation of the ER diagram in figure 3 to the tables below. Hint: to ensure a minimal number of changes to the database, consider each table in the order it appears below.

### Power Plant

<table>
<thead>
<tr>
<th>plant number</th>
<th>type</th>
<th>capacity (MW-h/Month)</th>
<th>current age</th>
<th>maximum age</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>nuclear</td>
<td>16,000</td>
<td>25</td>
<td>50</td>
</tr>
<tr>
<td>2</td>
<td>solar</td>
<td>5,000</td>
<td>5</td>
<td>85</td>
</tr>
</tbody>
</table>

### Water Structure

<table>
<thead>
<tr>
<th>structure number</th>
<th>type</th>
<th>capacity ($m^3$/month)</th>
<th>current age</th>
<th>maximum age</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>pumping station</td>
<td>1,500</td>
<td>10</td>
<td>100</td>
</tr>
<tr>
<td>2</td>
<td>pumping station</td>
<td>1,500</td>
<td>20</td>
<td>100</td>
</tr>
<tr>
<td>3</td>
<td>water treatment plant</td>
<td>60,000</td>
<td>20</td>
<td>70</td>
</tr>
<tr>
<td>4</td>
<td>desalination plant</td>
<td>5,000</td>
<td>20</td>
<td>100</td>
</tr>
</tbody>
</table>

### Garbage Structure

<table>
<thead>
<tr>
<th>structure number</th>
<th>type</th>
<th>capacity (tons/month)</th>
<th>current age</th>
<th>maximum age</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>incinerator</td>
<td>4,500</td>
<td>20</td>
<td>80</td>
</tr>
<tr>
<td>2</td>
<td>recycling center</td>
<td>2,200</td>
<td>20</td>
<td>75</td>
</tr>
</tbody>
</table>

### Zone

<table>
<thead>
<tr>
<th>zone number</th>
<th>trash production (tons/month)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1,250</td>
</tr>
<tr>
<td>2</td>
<td>2,220</td>
</tr>
<tr>
<td>3</td>
<td>1,250</td>
</tr>
<tr>
<td>4</td>
<td>2,000</td>
</tr>
<tr>
<td>5</td>
<td>990</td>
</tr>
</tbody>
</table>

### Residential Zone

<table>
<thead>
<tr>
<th>zone number</th>
<th>population</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3,252</td>
</tr>
<tr>
<td>2</td>
<td>1,336</td>
</tr>
</tbody>
</table>

### Commercial Zone

<table>
<thead>
<tr>
<th>zone number</th>
<th>avg. land value</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>$5,000</td>
</tr>
</tbody>
</table>

### Industrial Zone

<table>
<thead>
<tr>
<th>zone number</th>
<th>avg. pollution level</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>high</td>
</tr>
</tbody>
</table>
### Road

<table>
<thead>
<tr>
<th>road ID</th>
<th>last maintenance</th>
<th>last resurfacing</th>
<th>type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>06/06/2020</td>
<td>01/01/2000</td>
<td>highway</td>
</tr>
<tr>
<td>2</td>
<td>06/06/2020</td>
<td>01/01/2000</td>
<td>highway</td>
</tr>
<tr>
<td>3</td>
<td>07/15/2021</td>
<td>01/01/2001</td>
<td>highway</td>
</tr>
<tr>
<td>4</td>
<td>07/15/2021</td>
<td>01/01/2001</td>
<td>highway</td>
</tr>
<tr>
<td>5</td>
<td>08/08/2015</td>
<td>01/01/2002</td>
<td>highway</td>
</tr>
</tbody>
</table>

### Building / Located Within

<table>
<thead>
<tr>
<th>building number</th>
<th>zone number</th>
<th>power consumption (MW-h/Month)</th>
<th>water consumption (m³/month)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>5,260</td>
<td>2,220</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>3,800</td>
<td>2,200</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>4,000</td>
<td>1,250</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>4,250</td>
<td>1,900</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>5,500</td>
<td>1,550</td>
</tr>
<tr>
<td>1</td>
<td>4</td>
<td>1,500</td>
<td>660</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>1,500</td>
<td>680</td>
</tr>
</tbody>
</table>

### Power Production/Consumption

<table>
<thead>
<tr>
<th>plant number</th>
<th>zone number</th>
<th>building number</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>4</td>
<td>1</td>
</tr>
</tbody>
</table>

### Water Production/Consumption

<table>
<thead>
<tr>
<th>structure number</th>
<th>zone number</th>
<th>building number</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>1</td>
</tr>
</tbody>
</table>

### Trash Disposal

<table>
<thead>
<tr>
<th>zone number</th>
<th>truck number</th>
<th>structure number</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>1</td>
</tr>
</tbody>
</table>

### Runs Between (C-R)

<table>
<thead>
<tr>
<th>Road ID</th>
<th>C Zone number</th>
<th>R Zone number</th>
<th>traffic flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>1</td>
<td>heavy</td>
</tr>
</tbody>
</table>
Solution: We consider the constraints on a table-by-table basis. Note that since relationship tables involve composite keys (from participating entity sets), we have additional foreign key constraints not shown explicitly in the ER diagram given.

- Power Plant: The only constraint on this table is that “plant number” must be a primary key. This is satisfied.
- Water Structure: Similarly, the only constraint is that “structure number” is a primary key. This is satisfied.
- Garbage Structure: Again, the only constraint is that “structure number” is a primary key. This is satisfied.
- Zone: The only constraint is that “zone number” is a primary key. This is violated because there are two tuples that appear with a value of “1” for “zone number”. One of these must be deleted.
- Residential Zone: There are two constraints on this table: “zone number” must be both a primary key and a foreign key referencing the Zone table (i.e. every zone number appearing must also appear in the Zone table). Both constraints are satisfied.
- Commercial Zone: As for Residential Zone (all constraints satisfied).
- Industrial Zone: As for Residential Zone (all constraints satisfied).
- Road: The only constraint is that “Road ID” is a primary key. This is satisfied.
- Building / Located Within: Since a Building is a weak entity, the building number together with the zone number must be a primary key for this table. This constraint is satisfied. Furthermore, “zone number” must be a foreign key, referencing the Zone table. This constraint is violated, because the value “5” appears as a zone number, but there is no such zone number in the Zone table. The tuple (2, 5, 1500, 680) should be deleted.
- Power Production / Consumption: There are four constraints for this table: (i) “plant number” is a foreign key referencing Power Plant, (ii) “zone number” and “building number” together are a foreign key referencing the
Building/Located Within table, (iii) every building must appear in this table (total participation), and (iv) the three fields taken together must be a primary key.

Constraints (i), (ii) and (iv) are satisfied. However, there is no tuple for the building whose key is “building number = 2” and “zone number = 2”. Thus constraint (iii) is violated.

- **Water Production / Consumption**: Again, there are four constraints: (i) “structure number” is a foreign key for Water Structure, (ii) “zone number” and “building number” are a foreign key for Building/Located Within, (iii) every building must appear in this table, and (iv) the three fields must form a primary key.

Constraints (i), (ii) and (ii) are satisfied. Assuming the tuple (2, 5, 1500, 680) has been deleted (since it did not satisfy the constraints), then constraint (iii) is also satisfied.

- **Trash Disposal**: There are five constraints here: (i) “structure number” is a foreign key referencing Garbage Structure, (ii) “zone number” is a foreign key referencing Zone, (iii) every zone must participate in this relationship, (iv) each zone must participate only once in this relationship, and (v) the three fields must form a primary key.

Constraints (i), (ii), (iv), and (v) are satisfied. However, zone 3 does not appear in this table, so constraint (iv) is violated.

- **Road Between (C-R)**: There are five constraints here: (i) “road ID” is a foreign key referencing Road, (ii) “CZone number” is a foreign key referencing Commercial Zone, (iii) “Rzone number” is a foreign key referencing Residential Zone, (iv) every commercial zone must participate in this relationship, (v) every residential zone must participate in this relationship.

Constraints (i), (ii), (iii), and (iv) are satisfied. However, since residential zone 2 does not participate, constraint (v) is violated.

- **Road Between (2) (C-I)**: Similarly, there are five constraints here: (i) “road ID” is a foreign key referencing Road, (ii) “CZone number” is a foreign key referencing Commercial Zone, (iii) “Izone number” is a foreign key referencing Industrial Zone, (iv) every industrial zone must participate in this relationship, (v) every commercial zone must participate in this relationship.

Constraints (i), (ii), (iv) and (v) are satisfied. Constraint (iii) is violated since “1” is not an industrial zone.

- **Road Between (3) (R-I)**: There are also five constraints here: (i) “road ID” must be a foreign key referencing Road, (ii) “RZone number” is a foreign key referencing Residential Zone, (iii) “Izone number” is a foreign key referencing Industrial Zone, (iv) every industrial zone must participate in this relationship, (v) every residential zone must participate in this relationship.

All constraints are satisfied.

(c) Are there constraints that make sense for the city works database that are *not*
already expressed in the ER diagram? Identify two such constraints, and determine whether the diagram could be modified to include these constraints. If not, briefly explain. Note: You need not have extensive knowledge of a city works system to answer this question. If your constraints generally make sense based on the information in the existing diagram, that will suffice. Assume all dates are correct (even if they occur in the future).

**Solution:** There are many such constraints. Some take the form of age restrictions: for example, a power plant’s current age should not exceed its maximum age. Others take the form of capacity restrictions: for example, the combined power consumption of all buildings receiving power from a certain power plant should not exceed the capacity of that power plant. Neither type of constraint is appropriate in an ER diagram; each is better handled in SQL (with aggregation and triggers, both of which we’ll see later in the course).

(d) Suppose we want to represent the additional constraints that every road *must* run between two zones of different type, but not every road runs between two zones of *every* type. (So, for example, there may be a road running between a residential and an industrial zone, satisfying the first constraint, but this road does not run between a residential zone and a commercial one, so membership is not total in all three “runs between” relationships).

i. Can you represent these constraints by modifying the existing ER diagram? Hint: use aggregation (pages 37-38 in your text).

**Solution:** To capture these constraints, we use aggregation to group the three “runs between” relationships and the zone types. Then we can have a single, total relationship between the road entity and this aggregate entity. This situation is depicted in figure 2.

ii. Can these constraints be included in the diagram *without* aggregation? Give a brief justification of your answer.

**Solution:** I would say no, these constraints cannot be captured in the current diagram without aggregation. The constraints behave differently for different individual road entities so (as in the answer to 1(b)) they cannot be expressed without recourse to aggregation.
Figure 2: Using aggregation to capture constraints.
Figure 3: ER diagram for city works. Inspiration: Sim City 3000.